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ABSTRACT

From 1986 through 1993, boat electrofishing, fyke nets, beach seines, and gill nets were used to capture and mark 6,534 Arctic grayling *Thymallus arcticus* in Fielding Lake. The Jolly-Seber capture-recapture estimator was used to estimate abundance, survival rate, and recruitment for 1986 through 1992. Abundance estimates (fish ≥ 200 millimeter fork length) ranged from 4,356 fish (SE = 932 fish) in 1987 to 14,030 fish (SE = 2,576 fish) in 1991. Annual survival rate ranged from 0.53 in 1991 (SE = 0.12) to 0.85 in 1987 (SE = 0.11), while recruitment ranged from 808 fish (SE = 568 fish) in 1986 to 7,013 fish (SE = 1,855 fish) in 1990. Although age 2 through age 5 fish are not fully recruited to the defined population, age 5 was the most abundant age class in 1988 and 1989; age 3 was the most abundant age class in 1990 and 1991; and, age 4 was the most abundant age class in 1992 and 1993. No significant ($\alpha = 0.05$) differences in abundance, survival rate, or recruitment were detected during 1988 through 1991. Recruitment did decline significantly between 1991 and 1992. Instantaneous rates of fishing and natural mortality averaged 0.16 and 0.32 from 1986 through 1991. The average annual exploitation rate of 13 percent appears to be sustainable.

KEY WORDS: Arctic grayling, *Thymallus arcticus*, abundance, survival rate, recruitment, age composition, size composition, Relative Stock Density, maturity, sex composition, instantaneous mortality rates, Fielding Lake.

INTRODUCTION

Fielding Lake (63°10′ N, 145°58′ W; Figure 1) presents an ideal situation for research on Arctic grayling *Thymallus arcticus* in the lacustrine environment. It is an ideal place for two reasons. First, research on Arctic grayling in interior Alaska has emphasized the estimation of dynamic rates of the heavily exploited riverine stocks near Fairbanks and Delta Junction. Only recently have research efforts been devoted to lacustrine stocks of Arctic grayling in interior Alaska (Clark 1990, and Ridder 1990). Quantitative information on lacustrine stocks is needed so that the Department can effectively manage Arctic grayling fisheries in lakes. Moreover, this information can be used for comparisons to data from riverine stocks of Arctic grayling. Second, Fielding Lake is ideal for Arctic grayling research because of its relatively small size (538 ha), its proximity to a major road system (only 3.2 km off the Richardson Highway), and its single lake basin. These attributes allow cost effective and relatively precise estimates of abundance, survival rate, and recruitment to be made on a yearly basis.

Research on Arctic grayling in Fielding Lake began in 1986. Using a Jolly-Seber (Seber 1982) estimator and sampling design, quantitative estimates of abundance, survival, and recruitment have been calculated annually for 1986 to 1993. With these data and associated age, size, and sex composition information, a reasonably complete picture of the Fielding Lake Arctic grayling stock can be formulated.

Background

Fielding Lake supports a recreational fishery that targets on Arctic grayling, lake trout *Salvelinus namaycush*, burbot *Lota lota*, and round whitefish *Prosopium cylindraceum*. Harvests of Arctic grayling are numerically most abundant of the four species utilized in the fishery at Fielding Lake. Over the past 10 years, anglers have taken an annual average of 1,408 Arctic grayling and expended an annual average of 1,551 days of fishing effort (Mills 1982-1993; Table 1). Recreational fishing for Arctic grayling begins with ice-out each year (Clark and Ridder 1987a). The heaviest fishing pressure usually occurs during a two week period in early July (Clark and Ridder 1987a). Although not currently a major Arctic grayling fishery in interior Alaska, road access and the availability of quality Arctic grayling fishing make Fielding Lake potentially susceptible to increased fishing effort in the future.

Quantitative research on Arctic grayling in Fielding Lake was initiated in 1986 (Clark and Ridder 1987b). Prior to 1986, investigations of Arctic grayling in Fielding Lake were confined to spawning habits (Warner 1955b) and creel sampling to determine sport angling pressure and success rates (Warner 1959; Peckham 1977, 1983, 1984, 1985; Holmes et al. 1986; Clark and Ridder 1987a; and Baker 1988).

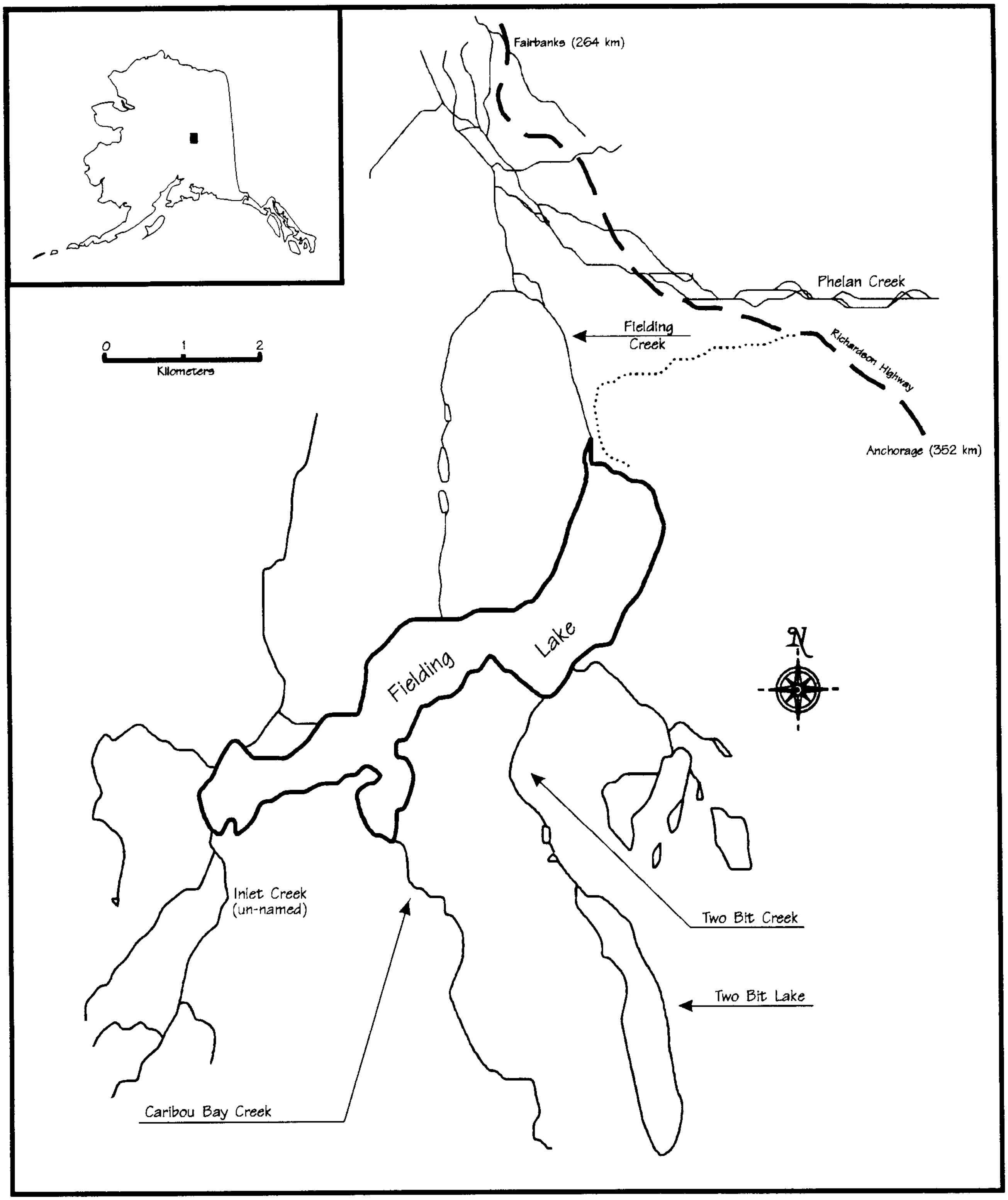

Figure 1. Fielding Lake and its tributary streams.

Table 1. Summary of total angling effort and Arctic grayling harvest at Fielding Lake, 1981-1992 (Mills 1982-1993).

Year	Total Angler-days	Arctic Grayling Harvest (number of fish)
1981	1,369	1,913
1982	2,764	3,044
1983	1,737	2,035
1984	871	935
1985	1,023	1,023
1986	1,682	1,329
1987	1,032	910
1988	1,728	1,492
1989	1,664	1,283
1990	1,255	1,097
1991	1,572	1,284
1992	1,910	548
Averages	1,551	1,408

Stock Assessment Goals and Objectives

The long-term goals of stock assessment at Fielding Lake are to:

1) accurately and precisely describe the stock status of Fielding Lake Arctic grayling on an annual basis;

2) use stock status data in models that predict the consequences of regulatory actions or changes in recreational fishing pressure; and,

3) provide fishery managers with stock status data and model results, so that informed management decisions can be made.

As part of attaining the first stock assessment goal, the objectives of research efforts in 1993 were to estimate:

1) abundance of Arctic grayling greater than 199 mm fork length (FL) in Fielding Lake;

2) age composition of the Arctic grayling population in Fielding Lake; and,

3) size composition of the Arctic grayling population in Fielding Lake.

In addition, survival rate, recruitment, sex ratio, maturity at age, maturity at length, tag shedding rate, and instantaneous mortality rates were estimated from data collected during 1986 through 1993.

METHODS

Sampling Gear and Techniques

Fyke nets, seines, gill nets, and electrofishing gear were used to capture Arctic grayling in Fielding Lake during late June of 1986 through 1993. Fyke nets used in Fielding Lake were the New Hampshire style with 10 mm meshes. Fyke nets were used in two ways. One method was to place the net out from shore with a 10 to 15 m lead stretching from the throat of the trap to the shore. Fish moving along the shore of the lake would be guided into the trap. A second method of deployment was to block off inlet creeks at their mouths. Wings (4.5 m long) were attached to the fyke nets and they were anchored along the banks of the lake inlets with the throat facing upstream. Arctic grayling migrating downstream after spawning were caught with these "fyke weirs."

Seines were used to capture Arctic grayling in the outlet of Fielding Lake and one of the inlets (Caribou Bay Creek; see Figure 2) during 1986 through 1988. These seines were 15 m * 2 m with 10 mm mesh and a 1 m deep bag. Arctic grayling were captured by hauling the seine downstream with the current, and then sweeping the seine towards shore. The area sampled averaged 30 m in length. In 1987, a large seine (30 m * 3 m with 25 mm mesh) was used to capture Arctic grayling in Fielding Lake. One end of the seine was anchored

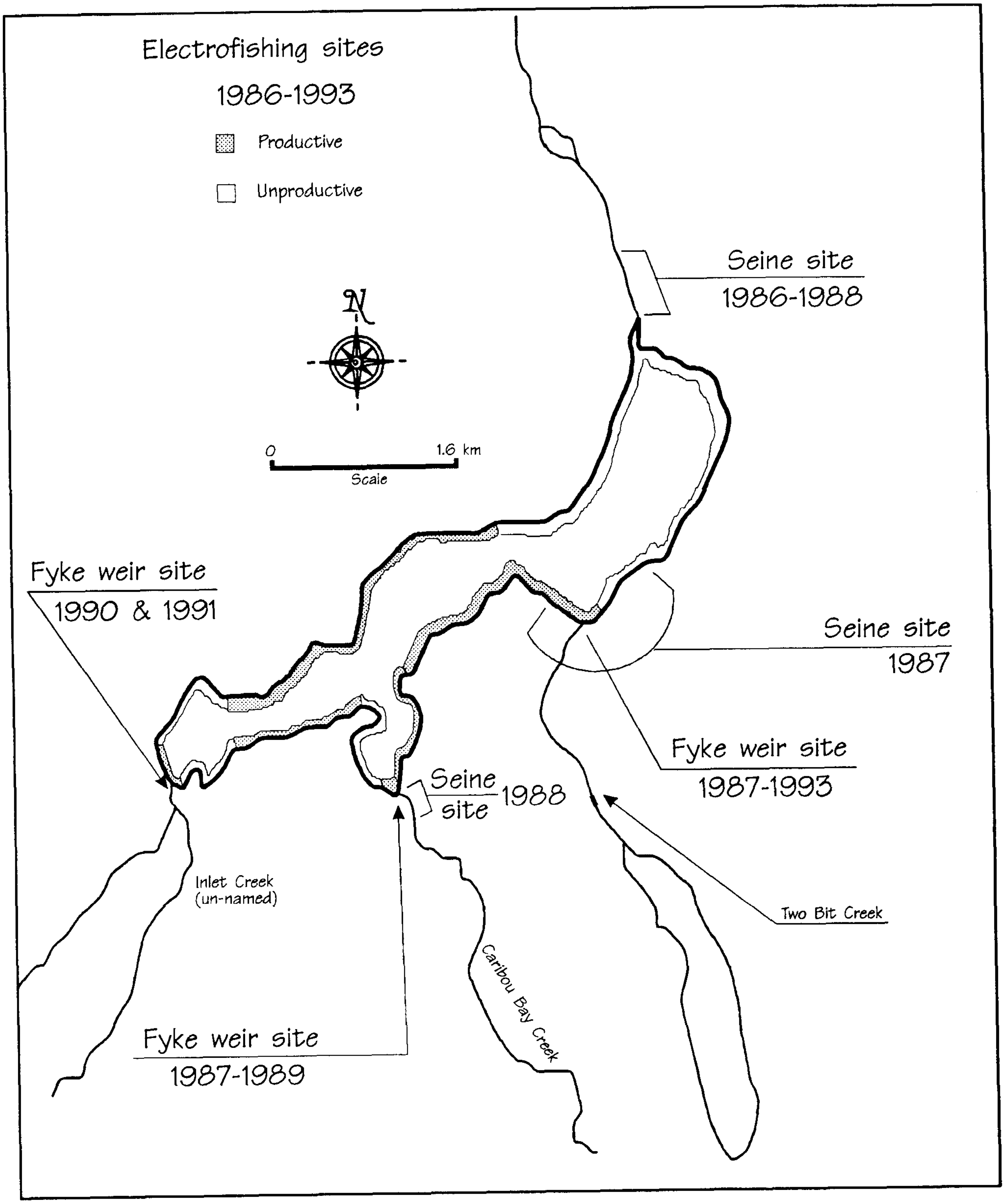

Figure 2. Sampling sites at Fielding Lake during 1986 through 1993.

on shore and the body of the seine was pulled into the lake with a gas-powered boat. The free end of the seine was retrieved by hand. Due to manpower constraints and low catch rate, seining was not performed during 1989 through 1993.

Gill nets were used in 1989 to capture lake trout in Fielding Lake in 1989. Arctic grayling were incidentally captured along with round whitefish. These nets were 30 m × 3 m with 25 mm mesh and were deployed perpendicular to the shoreline approximately 10 to 15 m from shore. Nets were checked once every hour.

Pulsed direct-current (DC) and alternating-current (AC) electrofishing boats were used to capture Arctic grayling during 1986 through 1988. Pulsed-DC electrofishing was used exclusively from 1989 through 1993. Both types of electrofishing current were used from 6.1 m river boats fitted with a 3 m long "T-boom" attached to a platform at the bow of the boat. Anodes were constructed of 9.5 mm diameter and 1.5 m long twisted steel cable, or 12.5 mm diameter and 1.5 m long flexible conduit filled with lead shot. On the DC system, the aluminum hull of the boat was used as the cathode. Input voltage (120 VAC) was provided by a 3,500 or 4,000 W single-phase gas powered generator. A variable voltage pulsator was used to generate output current. Output voltages during sampling varied from 200 to 300 VDC and 150 to 185 VAC. Amperage varied from 2.0 to 4.0 amp using DC and 1.0 to 2.0 amp using AC. Duty cycle was held constant at 40%. Pulse rate was held at 80 Hz from 1986 through 1988 and held at 60 Hz from 1989 through 1993.

Sampling with electrofishing boats was conducted along the shoreline of Fielding Lake during hours of darkness (2300 through 0300 hours). Although most of the shoreline of Fielding Lake was sampled with electrofishing gear during all seven years, greatest catches of Arctic grayling occurred on the windward side of the lake and over cobble and boulder substrate (Figure 2). To reduce capture-related stress, Arctic grayling were held in an aerated holding tub and subsequently transferred to a 2.4 m × 1.2 m with 10 mm mesh holding pen anchored near the lake shore. Fish were sampled for age, sex, maturity, and length within 24 hours of capture.

Regardless of sampling gear, each captured Arctic grayling was measured to the nearest 1 mm FL. Sex was determined by external morphology as described in Clark and Ridder (1987b) or by the presence of gametes. A sample of two scales was taken from an area approximately six scale rows above the lateral line just posterior to the insertion of the dorsal fin of each newly captured Arctic grayling and mounted on a gummed card. The gum cards were used to make triacetate impressions of the scales (30 seconds at 137,895 kPa, at a temperature of 97°C). Ages were determined by counts of annuli from impressions of scales magnified to 40X with the aid of a microfiche reader. Criteria for determining the presence of an annulus were: 1) complete circuli cutting over incomplete circuli; 2) clear areas or irregularities in circuli along the anterior and posterior fields; and, 3) regions of closely spaced circuli followed by a region of widely spaced circuli (Kruse 1959). Arctic grayling greater than 199 mm FL were marked with individually numbered internal anchor tags (Floy FD-68 or FD-67) inserted at the base of the dorsal fin. Tag shedding was controlled for with the use of a unique fin clip for each year of sampling. Arctic grayling exhibiting signs of injury or imminent mortality were immediately sacrificed.

Population Abundance, Survival, and Recruitment

A Jolly-Seber multiple capture-recapture study was initiated at Fielding Lake in 1988 to alleviate problems inherent with single-sample abundance estimators (Clark 1990). Capture-recapture data collected in 1986 (Clark and Ridder 1987b) and 1987 (Clark and Ridder 1988) during single-sample experiments were also used to estimate abundance in 1987 and 1988 (Clark 1989). As of 1992, Clark (1993) had used the Jolly-Seber estimator for abundance, survival, and recruitment estimates in 1987 through 1991.

Following the methodology of Clark (1993) for estimation of abundance, survival, and recruitment of Arctic grayling in Fielding Lake, the Jolly-Seber model for a demographically open population (Seber 1982, chapter 5.1) was used to obtain estimates of these parameters for 1986 through 1992. Updates of parameter estimates for 1986 through 1991 (see Clark 1993) were obtained.

The assumptions necessary for reliable estimation of the parameters are (from Seber 1982, page 196):

1) all Arctic grayling (≥ 200 mm FL) in the population have the same probability of being caught in the *i*th sample;

2) all Arctic grayling in the population have the same probability of surviving from the *i*th to the (i+1)th sample;

3) all Arctic grayling caught in the ith sample have the same probability of being released alive into the population;

4) all marked Arctic grayling do not lose their marks and all marks are reported on recovery; and,

5) all samples are instantaneous and each release is made immediately after the sample.

Assumptions 1 and 2 are central to reliable parameter estimation. However, changes in survival rate cannot be separated from changes in capture probability. These assumptions were tested for marked fish with a goodness-of-fit test devised by Pollock et al. (1985) and implemented in a modified form in program JOLLY (Pollock et al. 1990, page 22). The test is composed of two sets of chi-square contingency tables, the first "component" compares the rate of recapture of fish first captured before the *i*th sample with those first captured in the *i*th sample. The second component compares the rate of recapture of fish first captured before the (i-1)th sample with those first captured in the (i-1)th sample. For eight samples (1986-1993) there would be six contingency tables from the first component and five contingency tables from the second component. A nonsignificant test statistic would imply that the recapture rates were consistent among samples. If unmarked fish behave as do marked fish then the data would fit the Jolly-Seber model. Additionally, the Jolly-Seber model assumes that fish that emigrate from the population, either by dying, leaving Fielding Lake, or having a capture probability of 0, do so permanently. Temporary emigration (i.e., "leaving" and then "returning") from the population could severely bias estimates of survival. To test for temporary emigration, Balser (1981) devised a series of chi-square contingency tables that quantify the probability of marked fish that are unavailable for capture after the *i*th sample and remain so until the (*i*+*t*)th sample of the experiment. This test was used on capture-recapture data from Fielding Lake.

Assumption 3 was assumed to be valid because none of the sampling gears exhibited size selective mortality and numbers of dead or live unmarked fish were small. Assumption 4 was met by double marking of Arctic grayling with Floy tags and fin clips by sampling event (adipose fin in 1986 and 1992; partial upper caudal fin in 1987; partial right ventral fin in 1988; partial lower caudal fin in 1989; partial left pectoral fin in 1990; partial right pectoral fin in 1991; and, partial left ventral fin in 1993). Assumption 5 was met by restricting each sampling event to 10 days or less during the open water season.

Abundance and survival rate were estimated for 1986 through 1992 by first estimating the number of Arctic grayling marked in *i*th sample that survived to the (*i*+1)th sample:

$$\hat{M}_i = \frac{R_i z_i}{r_i} + m_i, \quad (i = 2, 3, \ldots, s\text{-}1) \qquad (1)$$

where: R_i = the number of marked Arctic grayling released after the *i*th sample;
z_i = the number of different Arctic grayling caught before the *i*th sample, not seen during the *i*th sample, but subsequently recaptured;
r_i = the number of Arctic grayling subsequently recaptured that were released in the *i*th sample (recaptures from R_i);
m_i = the number of marked Arctic grayling caught during the *i*th sample (recaptures); and,
s = the number of capture events.

With estimates of M_i, survival rate ($\hat{\phi}_i$) can be calculated from the relation of those surviving to those initially marked and released:

$$\hat{\phi}_i = \frac{\hat{M}_{i+1}}{\hat{M}_i - m_i + R_i}, \quad (i = 2, 3, \ldots, s\text{-}2) \qquad (2.1)$$

and for time period 1 (1986 to 1987) specifically,

$$\hat{\phi}_1 = \frac{\hat{M}_2}{R_1} \qquad (2.2)$$

Abundance (N_i) is then calculated by substituting estimated marks alive for marks released in a standard Petersen estimate:

$$\hat{N}_i = \frac{\hat{M}_i n_i}{m_i}, \quad (i = 2, 3, \ldots, s\text{-}1) \tag{3}$$

where: n_i = the number of Arctic grayling caught during the ith sample.

If assumption 2 does actually apply to unmarked fish, then the estimated number of recruits added to the population between the ith sample and (i+1)th sample and surviving to the (i+1)th sample (B_i) becomes:

$$\hat{B}_i = \hat{N}_{i+1} - \hat{\phi}_i\left(\hat{N}_i - n_i + R_i\right), \quad (i = 2, 3, \ldots, s\text{-}2) \tag{4}$$

Point estimates were calculated by two similar methods. The first method used program RECAP (Buckland 1980) to estimate the parameters. This method also calculates estimates of variance for the parameters. The second method bootstrapped (Efron 1982) the point estimation procedure of program RECAP and gave bootstrap estimates of the parameters and variances. Bootstrapping was used to resample the capture histories of all Arctic grayling captured during 1986 through 1993 1,000 times. The following protocol was used:

1) generate a psuedorandom number (between 0 and 1) from a uniform distribution;

2) sample the capture history of fish number "random number" × "total number of capture histories" + 1;

3) repeat 1 and 2, with replacement, until a sample of "total number of capture histories" is taken;

4) use program RECAP to generate parameter estimates for this iteration;

5) repeat 1 through 4 for 1,000 iterations; and,

6) calculate the bootstrap mean (standard arithmetic mean) and variance of the 1,000 estimates of each parameter.

Since abundance is not estimated for the first sample (1986) in this form of the Jolly-Seber model (see Seber 1982, page 201), but had been estimated in 1986 by Clark and Ridder (1987b), recruitment (B_{86}) was estimated for 1986 to 1987 by:

$$\hat{B}_{86} = \hat{N}_{87} - \hat{\phi}_{86}\hat{N}_{86} \tag{5}$$

Variance of B_{86} was estimated by replacing N_{87} and ϕ_{86} with their bootstrap estimates for each of the 1,000 iterations and calculating a mean and variance as discussed above. Abundance in 1986 (N_{86}) was held constant at 6,578 fish (Clark and Ridder 1987b) for all 1,000 iterations, so that the variance of B_{86} was considered a minimum estimate. Ninety-five percent confidence intervals were calculated from the 1,000 bootstrap iterations of the estimation procedure using the percentile method of Efron (1981).

Tag Shedding Rates

Although tag shedding can cause bias in estimation of survival rate (Pollock et al. 1990), double marking was employed at Fielding Lake to alleviate bias due to tag shedding. However, estimates of tag shedding rate are desirable for planning future capture-recapture experiments. Using double marks, tag shedding was estimated by the fraction of recaptured fish that had shed their tag or regenerated their fin clip. Since no complete regeneration of fin clips was evident throughout the eight year experiment, tag shedding rate (L_i) was restricted to the loss of internal anchor tags alone:

$$\hat{L}_i = \frac{t_k}{r_i} \tag{6}$$

where: $\hat{L}_i$ = the proportion of internal anchor tags shed from marked fish released during the ith sample;

t_k = the number of recaptured fish in the kth (after i) sample that had shed their tag; and,

r_i = the number of recaptured fish that were released in the ith sample.

From equation 6, estimates of tag shedding were calculated for year of release (ith sample) and for each year of recovery ($k = i + 1$, 2, 3, 4, 5, 6 samples). Estimates were summed by year of recovery and number of years at large. Variance of equation 6 was calculated by:

$$\hat{V}\left[\hat{L}_i\right] = \frac{\hat{L}_i\left(1 - \hat{L}_i\right)}{r_i - 1}. \tag{7}$$

Age and Size Composition

Collection of Arctic grayling for age-length samples was conducted in conjunction with capture-recapture sampling. Because estimates of abundance were germane to the time just before the ith sample, estimates of age and size composition used to apportion the abundance estimate by age or size group were taken from the ith sample. For example, the abundance estimate for 1987 was first calculated in 1988, but age composition from samples in 1987 were used to apportion abundance in 1987 into age and size groups.

Unadjusted age and size data were used to estimate age and size compositions for all samples. It was assumed that bias in age and size data was minimal if assumptions 1 and 2 of the Jolly-Seber estimator were being met. Also, Clark (1991) found no significant bias in length data collected during a Petersen experiment in 1990.

The proportion (p_j) of Arctic grayling in the sample that are age j was estimated by:

$$\hat{p}_j = \frac{y_j}{n} \tag{8}$$

where: y_j = the number of age j Arctic grayling sampled; and,
n = the total number of Arctic grayling sampled.

The unbiased variance of this proportion was estimated by:

$$\hat{V}[\hat{p}_i] = \frac{\hat{p}_i(1 - \hat{p}_i)}{n - 1} \tag{9}$$

Size composition of Arctic grayling in Fielding Lake was described with the incremental Relative Stock Density (RSD) indices of Gabelhouse (1984). The categories for RSD are based on a percentage of the word record length for Arctic grayling and are: Stock (150 to 269 mm FL); Quality (270 to 339 mm FL); Preferred (340 to 449 mm FL); Memorable (450 to 559 mm FL); and, Trophy (560 mm FL and longer). Because the defined population of Arctic grayling in Fielding Lake was 200 mm FL and longer, the stock RSD category was truncated to 200 to 269 mm FL. Equations 8 and 9 were used to estimate the proportion of fish and variance in each RSD category.

Partitioning of the Population:

In order to assess year-class strength of Arctic grayling in Fielding Lake it was necessary to partition the abundance, survival, and recruitment estimates into groups of ages that were deemed partially recruited or fully recruited into the defined population (those fish ≥ 200 mm FL). Two methods were used to assess the extent of recruitment by age. The first method involved calculation of age-specific survival rates by year of sampling (Appendices A1 and A2). This method resulted in survival rate estimates that were greater than unity (> 1.0) from age 3 through age 5 and less than unity for ages 6 through 9. Thus, recruitment by growth was indicated in ages 3 through 5. The second method involved a graphical method, plotting the length frequencies of fish at each age from data collected in 1986 through 1993. From this method, age 5 fish appear to be the youngest fully recruited age-class (Appendix A3). However, the Jolly-Seber method for estimation of recruitment defines recruitment as those fish added to the population between the ith sample and the $(i + 1)$th sample and surviving to the $(i + 1)$th sample (Seber 1982). Using this definition, it is evident that age 5 fish are not fully recruited between samples because not all age 4 fish are long enough to mark during the ith sample (some are less than 200 mm FL; Figure 3) and some of these insufficiently long age 4 fish recruit to the population as age 5 in the $(i+1)$th sample.

Based on these two methods, partially recruited fish are age 3 though age 5 and fully recruited fish are ages 6 through 10. Age 2 fish were removed from consideration in these partitions, since age 2 fish only appear in the population in 1986 (Clark and Ridder 1987b) and in 1990 through 1992.

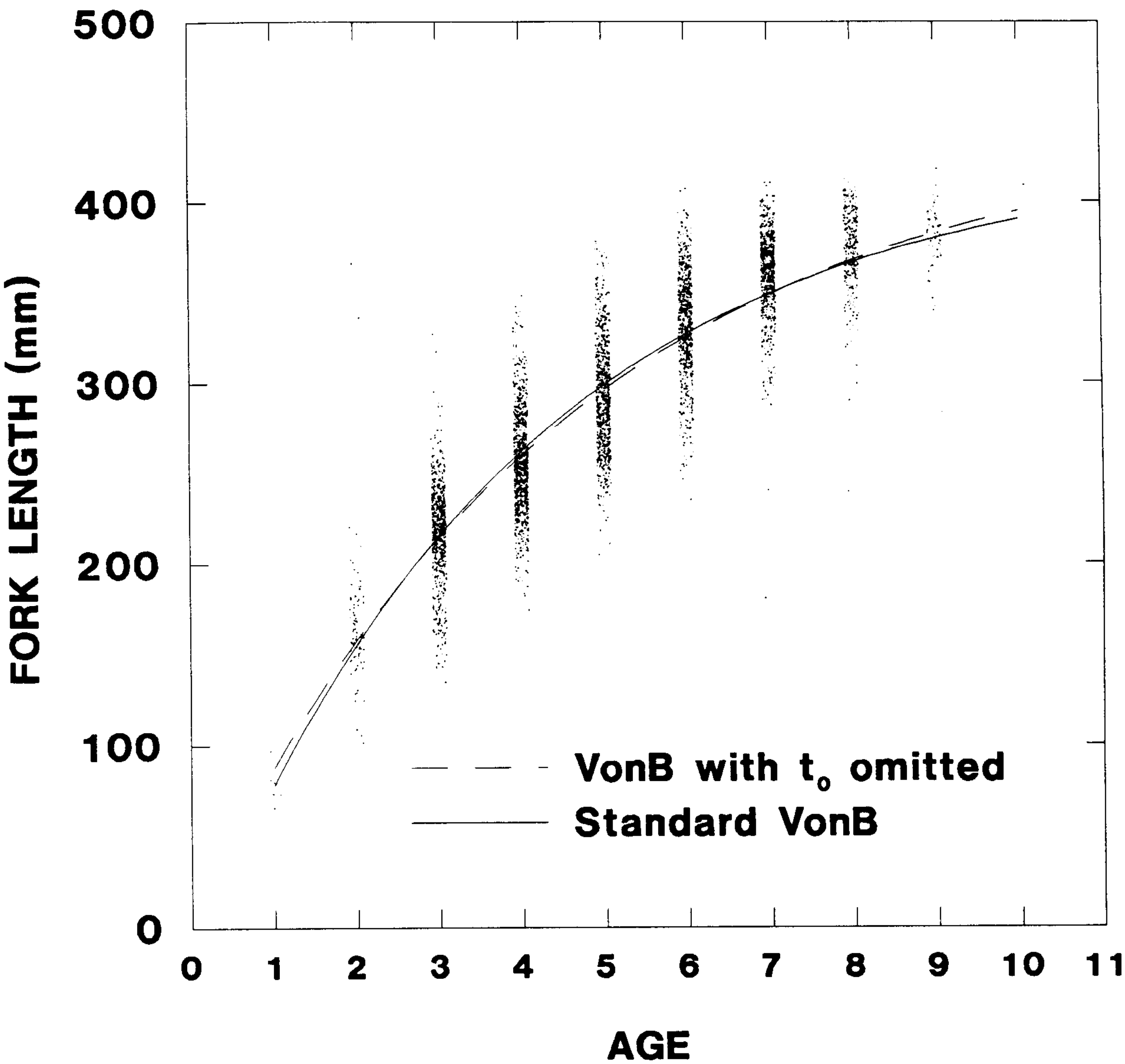

Figure 3. Sampled for length (mm) versus age and two growth curves used to describe mean fork length at age for Arctic grayling sampled from Fielding Lake during 1986 through 1993.

Abundance of fully recruited fish was estimated from abundance and age composition:

$$\hat{N}_{Fi} = \sum_{j=6}^{10} \hat{N}_{ji} \tag{10}$$

where:

$\hat{N}_{Fi}$ = the abundance of fully recruited Arctic grayling in year i;

$\hat{N}_{ji}$ = $\hat{p}_{ji} \cdot \hat{N}_i$;

$\hat{p}_{ji}$ = the proportion of Arctic grayling at age j in year i; and,

j = age 6, 7, ..., 10.

Variance of abundance of fully recruited fish was estimated by summing the estimated variances of age-class abundances:

$$\hat{V}\left[\hat{N}_{Fi}\right] \approx \sum_{j=6}^{10} \hat{V}\left[\hat{N}_{ji}\right] \tag{11}$$

where (from Goodman 1960):

$$\hat{V}\left[\hat{N}_{ji}\right] = \hat{p}_{ji}^2 \hat{V}\left[\hat{N}_i\right] + \hat{N}_i^2 \hat{V}\left[\hat{p}_{ji}\right] - \hat{V}\left[\hat{N}_i\right]\hat{V}\left[\hat{p}_{ji}\right] \tag{12}$$

Abundance of partially recruited Arctic grayling (age 3 through age 5) was estimated by summing age-class abundances for ages 3 through 5:

$$\hat{N}_{Pi} \approx \sum_{j=3}^{5} \hat{N}_{ji} \tag{13}$$

where:

$\hat{N}_{Pi}$ = the abundance of partially recruited Arctic grayling in year i; and,

j = age 3, 4, 5.

Variance of this abundance estimate was calculated with equations 11 and 12, substituting j with j = age 3, age 4, and age 5.

Recruitment of fully recruited Arctic grayling was by definition the estimated abundance of age 6 fish in year i+1:

$$\hat{B}_{Fi} = \hat{N}_{6,i+1} \tag{14}$$

where:

$\hat{B}_{Fi}$ = the number of fully recruited Arctic grayling that were added to the population between year i and i+1 and were alive in year i+1; and,

$\hat{N}_{6i+1}$ = the number of age 6 Arctic grayling in the population in year i+1.

Variance of recruitment was simply the variance of estimated abundance of age 6 fish in year i+1:

$$\hat{V}\left[\hat{B}_{Fi}\right] = \hat{V}\left[\hat{N}_{6,i+1}\right] \qquad (15)$$

Recruitment of partially recruited Arctic grayling was calculated by subtracting the estimate of recruitment for fully recruited fish from the Jolly-Seber estimate of recruitment for the entire stock (≥ 200 mm FL). If age 2 fish were present in the abundance estimate, recruitment for the stock was adjusted by subtracting the abundance of age 2 fish from the Jolly-Seber recruitment estimate. The equation for this estimate was:

$$\hat{B}_{Pi} = \hat{B}_i - \hat{B}_{Fi} \qquad (16)$$

where:

$\hat{B}_{Pi}$ = the number of partially recruited Arctic grayling that were added to the population between year i and year i+1 and were alive in year i+1; and,

$\hat{B}_i$ = the number of Arctic grayling (≥ 200 mm FL) that were added to the population between year i and year i+1 and were alive in year i+1.

If age 2 fish were present in the abundance estimate, equation 16 reevaluated to:

$$\hat{B}_{Pi} = \hat{B}_i - \hat{B}_{Fi} - \hat{N}_{2,i+1} \qquad (17)$$

Variances were calculated by summing the estimates of recruitment from the Jolly-Seber estimate and from equation 15:

$$\hat{V}\left[\hat{B}_{Pi}\right] = \hat{V}\left[\hat{B}_i\right] + \hat{V}\left[\hat{B}_{Fi}\right], \text{ or } \hat{V}\left[\hat{B}_{Pi}\right] = \hat{V}\left[\hat{B}_i\right] + \hat{V}\left[\hat{B}_{Fi}\right] + \hat{V}\left[\hat{N}_{2,i+1}\right] \qquad (18)$$

Survival rate for fully recruited Arctic grayling was calculated by subtracting recruitment from abundance in year i+1 and dividing the result by abundance of fully recruited fish in year i:

$$\hat{\phi}_{Fi} = \frac{\hat{N}_{Fi+1} - \hat{B}_{Fi}}{\hat{N}_{Fi}} \qquad (19)$$

where:

$\hat{\phi}_{Fi}$ = the survival rate of fully recruited Arctic grayling between year i and i+1.

Estimates of abundance were considered highly uncorrelated so that variance of survival rate of fully recruited fish was approximated with the delta method (Seber 1982) for the quotient of two independent variables:

$$\hat{V}\left[\hat{\phi}_{Fi}\right] \approx \frac{\left(\hat{N}_{Fi+1} - \hat{B}_{Fi}\right)^2}{\hat{N}_{Fi}^2}\left[\frac{\hat{V}\left[\hat{N}_{Fi+1}\right] + \hat{V}\left[\hat{B}_{Fi}\right]}{\left(\hat{N}_{Fi+1} - \hat{B}_{Fi}\right)^2} + \frac{\hat{V}\left[\hat{N}_{Fi}\right]}{\hat{N}_{Fi}^2}\right] \tag{20}$$

Survival rate for partially recruited Arctic grayling was calculated in a similar way:

$$\hat{\phi}_{Pi} = \frac{\hat{N}_{Pi+1} - \hat{B}_{Pi}}{\hat{N}_{Pi}}. \tag{21}$$

Maturity and Sex Composition

Age and length at sexual maturity were estimated from data collected during June of 1988 through 1992. All Arctic grayling greater than 199 mm FL were examined for maturity by the presence of gametes or by external methods (Clark and Ridder 1987b). The data were stratified by assigned age or 10 mm length groups. The proportion of mature fish at age j or within a 10 mm length group j was estimated as:

$$\hat{q}_j = \frac{y_j}{n_j} \tag{22}$$

where:

y_j = the number of mature Arctic grayling at age or length group j; and,

n_j = the number of Arctic grayling examined for maturity at age or length group j.

The estimated proportions were used to estimate the percent mature at age or arithmetic mean length within a 10 mm group for the population with probit analysis (Finney 1971).

Sex composition was estimated directly from samples taken during 1987 through 1992. Fish examined and found to be mature were also assigned a sex, based on the presence of gametes or by external methods (Clark and Ridder 1987b). The proportion of mature Arctic grayling that were either male or female was estimated by dividing the number sampled of one sex by the total number of mature fish sampled. Variance was estimated by the binomial relation shown in equation 9. Because sex composition data were not collected in 1986, it was assumed that the average sex composition during the years 1987 through 1990 could be used to approximate the sex composition in 1986. To approximate the variance of sex composition in 1986, it was assumed that variance of sex composition in 1986 was similar to that of 1987, since total sample sizes and time of sampling in these two years were similar.

Partitioning of the Population:

Estimates of abundance of fully recruited Arctic grayling can be useful for determining population trends over time. However, estimates of mature Arctic grayling in Fielding Lake could be used to estimate return-per-spawner or estimate egg deposition if fecundity estimates were available. Thus, abundance of mature Arctic grayling in Fielding Lake from 1986 through 1991 was estimated from abundances at age, maturity at age, and sex composition data. The relation can be written as:

$$\hat{S}_i = \sum_{j=3}^{10} \hat{N}_{ji}\hat{q}_i\hat{s}_i \tag{23}$$

where:

$\hat{S}_i$ = the abundance of either mature male or mature female Arctic grayling in year i;

$\hat{N}_{ji}$ = the abundance of age j Arctic grayling in year i;

$\hat{q}_j$ = the proportion of age j Arctic grayling that are mature; and,

$\hat{s}_i$ = the proportion of either mature male or mature female Arctic grayling in year i.

Variance of abundance by sex for mature fish was estimated with the variance of a product (Goodman 1960).

Mortality Rates

In addition to estimation of survival rates, instantaneous rates of mortality were estimated for the five intervening 1 year periods between 1986 and 1991. Estimates of instantaneous fishing mortality could be used to assess the level of exploitation of Arctic grayling in Fielding Lake. Estimates of natural mortality could be used to assess the balance between growth and natural mortality rate. Both of these parameter estimates could be used to model the Arctic grayling population in Fielding Lake. Since survival rate estimates were calculated from bootstrapping, it seemed prudent to derive instantaneous rates from these bootstrap samples. Instantaneous rates of mortality could have been estimated from the partitioned population, although information on catch-at-age is lacking for 1988 through 1991.

Initially, instantaneous total mortality was calculated from the estimate of survival (Ricker 1975):

$$\hat{Z}_i = -\ln\left(\hat{\phi}_i\right) \tag{24}$$

where:

$\hat{Z}_i$ = the instantaneous rate of total mortality for Arctic grayling (≥ 200 mm FL) in year i; and,

$\hat{\phi}_i$ = the bootstrap estimate of survival rate in year i.

Next, the harvest of Arctic grayling in year i was taken from Mills (1987-1991) and used to estimate instantaneous fishing mortality. Harvest of Arctic grayling at Fielding Lake begins just after ice-out on the lake (mid-June; Clark and Ridder 1987a), so that the abundance estimate for year i was assumed to be the starting abundance for that fishing year. It was also assumed that natural mortality was occurring during the fishing season (June through September). The Baranov catch equation (Ricker 1975) with recruitment during fishing (Parker et al. 1989) was solved for fishing mortality by iteration until the estimated harvest (C_i) was within 1 fish of the harvest obtained from Mills (1987-1991):

$$C_i = \frac{F_i\left(1 - e^{-Z_i}\right)N_i}{Z_i} + \frac{F_i}{Z_i} B_i\left(e^{-Z_i} + Z_i - 1\right) \tag{25}$$

where:

C_i = the harvest of Arctic grayling in year i; and,
F_i = the instantaneous rate of fishing mortality in year i.

Assuming concurrent natural and fishing mortality, natural mortality rate was calculated by subtraction (natural mortality = total mortality - fishing mortality). Variances of total mortality were estimated by calculating the standard sampling variance of 1,000 bootstrap iterations of equation 24. Variances of fishing and natural mortality were approximated by Monte Carlo methods (see Clark in press). Using standard bootstrap technique, replicate estimates of total mortality, recruitment, and abundance were entered jointly into equation 25 1,000 times. Similarly, replicate estimates of harvest, provided by bootstrapping from Mills (unpublished data), were randomly entered (with replacement) into equation 25. This process resulted in 1,000 estimates of fishing and natural mortality calculated from 1,000 estimates of total mortality, recruitment and abundance, with error in estimates of harvest included. Variance was calculated from the 1,000 estimates of each mortality rate.

Age and Growth

Length at age data have been collected for Arctic grayling in Fielding Lake from 1986 to the present. Clark (1993) last estimated parameters of the von Bertalanffy growth model (Ricker 1975) in 1992, using data from 1986 through 1992. To reexamine growth of Arctic grayling in Fielding Lake, length and age data from 1986 through 1993 were used to estimate the arithmetic mean fork length and variance (based on standard estimating equations). Means of fork length at age were fitted to the von Bertalanffy growth model using a weighted nonlinear least squares procedure. Fitted parameters are:

1) L_∞ is the length an average fish could attain if life and growth continued indefinitely (Ricker 1975);

2) K is the Brody growth coefficient, a dimensionless variate that regulates incremental growth; and,

3) t_0 represents the hypothetical age at which a fish would have zero length (Ricker 1975).

The Marquardt (1963) compromise was used, as implemented in the SAS procedure NLIN (SAS 1988), weighted by the inverse of the standard error of mean length at age. Initial values for the parameters were sought by varying L_∞ from 350 to 700 mm FL by 50 mm increments; varying K from 0.0 to 0.4 by 0.01 increments; and, varying t_0 from -2.0 years to 2.0 years by 0.5 year increments. Of the 360 permutations of the parameter values, the combination of parameter values with the lowest weighted mean square error was used as initial values in the least squares procedure.

Historic Data Summary

Data collected from Fielding Lake (1953 to 1993) were summarized (Appendix B). Creel census estimates, catch distributions, population abundance estimates, length at age estimates, age composition estimates, and a growth model were summarized from Federal Aid in Sport Fish Restoration reports and State of Alaska Fishery Data Series reports written from 1955 to the present. When possible, estimates of precision were reported with point estimates. Precision was reported as either a standard error or the 95% confidence interval. Sample sizes were reported if neither of these estimates of precision were available. Research on spawning habits of Fielding Lake Arctic grayling was reported by Warner (1955b). In addition to the aforementioned state and federal reports, reports concerning Arctic grayling research in Alaska from 1952-1980 were compiled by Armstrong (1982); and, Armstrong et al. (1986) have compiled a bibliography for the genus *Thymallus* to 1985. Clark (in press) also presented an analysis of utility and yield-per-recruit of Arctic grayling in Fielding Lake from 1986 through 1991.

RESULTS

Parameter Estimates

Of 6,642 Arctic grayling captured, 6,534 fish were marked and released between 1986 and 1993 (Table 2). From those fish marked and released during 1986 through 1992, 626 recoveries were made during 1987 through 1993 (Table 3). No significant ($\alpha = 0.05$) departure was evident when these capture-recapture data were fitted to the Jolly-Seber model (Table 4). However, the test statistic for component 2 of the goodness-of-fit test for the 1990 sample ($i = 5$) did have a significant test statistic (Table 4). Chi-square cell values of the goodness-of-fit test indicate that the failure of fit was due equally to all the individual cell statistics (Appendix C1). Similarly, overall temporary emigration from the population was not detected (Table 5), but significant temporary emigration was detected for fish first captured during 1986 through 1989, not seen in 1990, but seen in 1991 through 1993 (see Appendix C2).

Estimates of survival rate varied from 0.53 in 1991 to 0.85 in 1987 (Table 6). Bootstrap estimates were similar to those calculated from a single run of program RECAP, differing by less than 2.0% for all five estimates of survival (Table 7). Abundance estimates varied from a low of 4,356 in 1987 to a high of 14,030 in 1991 (Table 6). Abundance in 1992 was 9,278 fish (SE = 2,054 fish). Abundance estimates generated from a single run of program RECAP were generally biased low, but biased less than 3.0% for all estimates (Table 7). Estimated recruitment into the population between samples varied from 1,910 fish in 1991 to 7,013 fish in 1990 (Table 6). However, if the Petersen estimate for 1986 is used (6,578 fish, SE = 1,150 fish), the lowest estimated recruitment was 903 fish (SE = 706 fish) in 1986. Bias in estimation of recruitment with a single run of program RECAP was less than 4.1% for all samples (Table 7).

Table 2. Summary of captures[a] of Arctic grayling with fyke, seine, and gill nets, and electrofishing gear in Fielding Lake during spring sampling, 1986 through 1993.

Year	Dates	Fyke Net[b]	Seine[c]	Gill Net[d]	Electro-fishing[e]	Total Marks
1986	24 June to 3 July	46	208	NU[f]	297	551
1987	16 to 21 June	221	25	NU	222	468
1988	13 to 20 June	50	30	NU	784	864
1989	22 to 26 June	33	NU	137	1,106	1,276
1990	12 to 21 June	78	NU	NU	1,035	1,113
1991	19 to 28 June	239	NU	NU	575	814
1992	15 to 20 June	0	NU	NU	730	730
1993	14 to 19 June	0	NU	NU	718	718
Total		667	263	137	5,467	6,534

[a] Captures are those Arctic grayling ≥200 mm FL, released alive, and bearing a Floy internal anchor tag.

[b] Fyke nets were deployed along the shoreline of Fielding Lake in 1986. In 1987, 1988, and 1989 fyke nets were deployed as weirs across Two Bit and Caribou Bay Creeks. During 1990 a fyke net was deployed across Two Bit Creek only. During 1991 fyke nets were deployed across Two Bit Creek and the Unnamed Creek. All fyke nets were similar to the New Hampshire style and had 10 mm mesh.

[c] Seining was done with 15 m × 2 m beach seines (10 mm mesh) primarily in Fielding Lake outlet. Some beach seining in Fielding Lake proper was done in 1987 with a 60 m × 3 m seine (25 mm mesh) near Two Bit Creek.

[d] Gill nets (33 m × 3 m; 25 mm mesh) were used to capture lake trout in 1989. Arctic grayling were incidentally caught in these gill nets.

[e] Electrofishing was performed with AC and pulsed-DC boat electrofishing units mounted on a 6.1 m riverboat (1986 through 1988). Pulsed-DC was used exclusively in 1989 through 1993.

[f] NU = gear type not utilized to capture Arctic grayling.

Table 3. Summary of captures, fish released with marks, and recaptures of Arctic grayling (≥ 200 mm FL) in Fielding Lake, 1986 through 1993.

Time of last capture	Time of recapture							
	1986	1987	1988	1989	1990	1991	1992	1993
1986	0	32	22	17	7	3	2	0
1987	0	0	40	32	8	7	2	1
1988	0	0	0	78	21	11	9	3
1989	0	0	0	0	97	28	12	10
1990	0	0	0	0	0	44	37	18
1991	0	0	0	0	0	0	34	18
1992	0	0	0	0	0	0	0	33
1993	0	0	0	0	0	0	0	0
Marked	0	32	62	127	133	93	96	83
Unmarked	551	437	812	1,198	985	741	645	647
Caught	551	469	874	1,325	1,118	834	741	730
Released	551	468	864	1,276	1,113	814	730	718

Table 4. Goodness-of-fit tests of capture-recapture data from Arctic grayling (≥ 200 mm FL) in Fielding Lake to the Jolly-Seber model with death and immigration, 1986 through 1993.

	Component 1[a]			Component 2[b]		
Year of sampling (*i*)	χ^2	*df*	*P*	χ^2	*df*	*P*
1987	0.288	1	0.592	---	---	---
1988	0.722	1	0.395	0.543	2	0.762
1989	0.031	1	0.860	0.533	2	0.766
1990	2.018	1	0.155	6.424	2	0.040
1991	0.007	1	0.932	3.417	2	0.181
1992	0.024	1	0.876	0.010	2	0.995
Totals	3.091	6	0.797	10.927	10	0.363
Overall	14.018	16	0.597	(Components 1 and 2)		

[a] Component 1 compares the frequency of first captures before the year of sampling ($<i$) with first captures from the year of sampling (i), stratified by whether these fish were subsequently recaptured versus not recaptured after the year of sampling (Pollock et al. 1985, 1990).

[b] Component 2 compares the frequency of first captures before the year $i-1$ ($<i-1$) that were not subsequently captured in year $i-1$, with those subsequently captured in year $i-1$; and, with those first captured in year $i-1$, stratified by whether these fish were captured in year i or they were not captured in year i, but captured after year i (Pollock et al. 1985, 1990).

Table 5. Tests for temporary emigration[a] in mark-recapture data from Arctic grayling (≥ 200 mm FL) in Fielding Lake, 1986 through 1993.

Sample of last capture[b]	Sample of subsequent capture[c]	χ^2	*df*	*P*
1986 vs. 1987	1988 and after 1988	0.02	1	0.888
1986 vs. 1987	1989 and after 1989	0.23	1	0.632
1986 vs. 1987	1990 and after 1990	0.56	1	0.454
1986 vs. 1987	1991 and after 1991	0.15	1	0.699
1986 vs. 1987	1992 and after 1992	0.84	1	0.359
1986-1987 vs. 1988	1989 and after 1989	0.08	1	0.777
1986-1987 vs. 1988	1990 and after 1990	0.04	1	0.842
1986-1987 vs. 1988	1991 and after 1991	1.30	1	0.254
1986-1987 vs. 1988	1992 and after 1992	0.05	1	0.823
1986-1988 vs. 1989	1990 and after 1990	6.17	1	0.013
1986-1988 vs. 1989	1991 and after 1991	0.00	1	0.950
1986-1988 vs. 1989	1992 and after 1992	2.00	1	0.157
1986-1989 vs. 1990	1991 and after 1991	2.35	1	0.125
1986-1989 vs. 1990	1992 and after 1992	0.01	1	0.752
1986-1990 vs. 1991	1992 and after 1992	0.00	1	0.953
Overall chi-squared		13.89	15	0.534

[a] Temporary emigration is defined as marked fish that are unavailable for capture after year i and remain so until time *j* (Balser 1981).

[b] Sample years tested for differences in the proportion of marks recovered in subsequent sample years (rows of chi-squared test).

[c] Sample years in which subsequent captures are made (columns of chi-squared test).

Table 6. Summary of parameter estimates from the Jolly-Seber model applied to capture-recapture data from Fielding Lake, 1986 through 1993.

Parameter[a]	Estimate	Standard Error	Lower 95% C.I.[b]	Upper 95% C.I.	CV[c]
ϕ_{86}	0.54	0.08	0.45	0.63	14.6
M_{86}	297	42	253	346	14.1
N_{87}	4,356	932	3,740	8,460	21.4
B_{87}	5,070	1,364	3,461	7,441	26.9
ϕ_{87}	0.85	0.11	0.71	0.97	13.4
M_{87}	621	75	519	707	12.0
N_{88}	8,761	1,466	6,614	11,532	16.7
B_{88}	3,297	968	1,752	5,228	29.4
ϕ_{88}	0.54	0.07	0.46	0.64	12.6
M_{88}	769	86	674	878	11.2
N_{89}	8,027	1,091	6,708	9,600	13.6
B_{89}	4,767	1,050	3,448	6,545	22.0
ϕ_{89}	0.59	0.08	0.49	0.71	13.3
M_{89}	1,122	138	968	1,313	12.3
N_{90}	9,434	1,368	7,834	11,403	14.5
B_{90}	7,013	1,855	5,415	9,463	26.4
ϕ_{90}	0.74	0.13	0.62	0.90	17.1
M_{90}	1,564	246	1,325	1,853	15.7
N_{91}	14,030	2,576	11,668	17,162	18.3
B_{91}	1,910	1,228	0	4,354	64.3
ϕ_{91}	0.53	0.12	0.34	0.67	22.9
M_{91}	1,202	242	894	1,514	20.2
N_{92}	9,278	2,054	6,805	12,499	22.1

[a] Parameter definitions are: ϕ_i = the proportion of marked Arctic grayling that survived from marking in year i to recapture in year $i+1$; M_i = the number of Arctic grayling marked up until year i that were alive just before sampling in year $i+1$; N_i = population size of Arctic grayling ≥ 200 mm FL prior to sampling in year i; and, B_i = the number of new Arctic grayling ≥ 200 mm FL that recruited to the population between year i and year $i+1$ and were alive in year $i+1$.

[b] 95% C.I. = the 95% bootstrap confidence intervals utilizing the percentile method (Efron 1981).

[c] CV = the coefficient of variation of the estimate, expressed as a percentage. Calculated as standard error/estimate x 100%.

Table 7. Comparison of Jolly-Seber and bootstrap estimates of Arctic grayling (≥ 200 mm FL) survival, marked fish at large, abundance, and recruitment in Fielding Lake, 1986 through 1992.

Parameter[a]	Jolly-Seber[b] Estimate	Bootstrap[c] Estimate	Bias (%)[d]
ϕ_{86}	0.54	0.55	1.2
M_{86}	297	300	1.2
N_{87}	4,356	4,493	3.0
B_{87}	5,070	5,043	0.5
ϕ_{87}	0.85	0.84	0.5
M_{87}	621	620	0.1
N_{88}	8,761	8,819	0.7
B_{88}	3,297	3,378	2.4
ϕ_{88}	0.54	0.54	0.7
M_{88}	769	773	0.5
N_{89}	8,027	8,141	1.4
B_{89}	4,767	4,774	0.1
ϕ_{89}	0.59	0.59	0.4
M_{89}	1,122	1,129	0.6
N_{90}	9,434	9,522	0.9
B_{90}	7,013	7,078	0.9
ϕ_{90}	0.74	0.75	0.2
M_{90}	1,564	1,569	0.3
N_{91}	14,030	14,136	0.8
B_{91}	1,910	1,991	4.1
ϕ_{91}	0.53	0.54	2.0
M_{91}	1,202	1,225	1.9
N_{92}	9,278	9,544	2.8

[a] Parameter definitions are: ϕ_i = the proportion of marked Arctic grayling that survived from marking in year i to recapture in year $i+1$; M_i = the number of Arctic grayling marked up until year i that were alive just before sampling in year $i+1$; N_i = population size of Arctic grayling ≥ 200 mm FL prior to sampling in year i; and, B_i = the number of new Arctic grayling ≥ 200 mm FL that recruited to the population between year i and year $i+1$ and were alive in year $i+1$.

[b] Jolly-Seber estimates were calculated with a single run of program RECAP of Buckland (1980).

[c] Bootstrap estimates were calculated by replicating the output of point estimates produced by program RECAP (Buckland 1980) 1,000 times (Efron 1982).

[d] Bias is the difference between the Jolly-Seber point estimate and the bootstrap mean from 1,000 replications of the capture history data expressed as a percentage: |Jolly-Seber - Bootstrap|/Bootstrap x 100%.

Although tag shedding was accounted for by double marking and rigorous examination of all captured fish, shedding rates for one year at large ranged from 2% (SE = 2%) to 13% (SE = 6%). When summed over all years of tagging, shedding rate for one year at large was 7% (SE = 1%; Table 8). Shedding rate increased to 15% (SE = 3%) at two years at large, and 23% (SE = 5%) at three years, dropped off to 17% (SE = 7%) at four years and 13% (SE = 13%) at five years.

Partitioning Of The Population, 1986-1992

When partitioned by age-class, maximum abundance at age varied from age 7 in 1986 and 1987, to age 5 in 1988 and 1989, to age 3 in 1990 and 1991, and to age 4 in 1992 and 1993 (Table 9). Shifts in age composition during the eight year estimation experiment were accompanied by shifts in size composition as well (Table 10). Stock size fish were most abundant in 1986, 1988 and 1990 through 1992, while quality size fish were dominant in the 1989 and 1993 samples. Preferred size fish were most abundant in the 1987 sample.

When the estimated parameters were partitioned into partially and fully recruited age groupings, estimated survival rate tended to be higher for partially recruited Arctic grayling (Table 11). However, survival rate of partially recruited fish in 1989 was less than that of fully recruited fish in the same year. For all years the estimated recruitment into the partially recruited segment of the population was more variable than recruitment for fully recruited fish (Table 11). Recruitment of fully recruited Arctic grayling in 1986 tended to be higher than the Jolly-Seber estimate of recruitment for the entire population that year. This was due to a negative value (-52 fish, SE = 602 fish) for recruitment of partially recruited fish in the same year.

Observed maturity increased with increasing length, with less than 1% maturity at 266 mm FL, 50% maturity at 319 mm FL, and 99% maturity at 383 mm FL (Table 12). Moreover, maturity at age increased from less than 1% at age 4 to 69% at age 6, and to 97% at age 9 (Table 12). After maturity was attained, the observed sex composition varied across the seven years of sampling (Table 13). On average 50% of mature fish were males and 50% were females. Because of the relatively similar proportions of each sex in the population, abundance of each sex varied principally with changes in age composition (Table 14). Abundance of males was lowest in 1989 and highest in 1991, while abundance of females was lowest in 1987 and highest in 1989.

Instantaneous rates of mortality were calculated for the six intervening periods between 1986 and 1992 (Table 15). Total mortality rate varied from 0.17 (SE = 0.08) in 1987 to 0.64 (SE = 0.17) in 1991. Fishing mortality rate did not vary considerably during the sampled years, ranging from 0.10 (SE = 0.05) in 1990 to 0.25 (SE = 0.11) in 1986. Natural mortality rate ranged from 0.03 (SE = 0.18) in 1987 to 0.53 (SE = 0.16) in 1991. Average instantaneous mortality rates for the seven year period were 0.48, 0.16, and 0.32 for total, fishing, and natural, respectively.

Table 8. Summary of estimates of tag shedding, calculated by duration at large and year of release, for Arctic grayling (≥200 mm FL) at Fielding Lake, 1986 through 1993.

Year of release	Total recovered							Tags shed by year							By years at large[a]						
	87	88	89	90	91	92	93	87	88	89	90	91	92	93	1	2	3	4	5	6	7
1986	32	23	16	9	3	2	0	1	4	10	3	1	1	0	1	4	10	3	1	1	0
p[b]								0.03	0.17	0.62	0.33	0.33	0.50	---							
SE[d]								0.03	0.08	0.12	0.17	0.33	0.50	---							
1987		38	28	12	7	2	1		5	8	1	1	0	0	5	8	1	1	0	0	
p									0.13	0.29	0.08	0.14	0	0							
SE									0.06	0.09	0.08	0.14	---	---							
1988			67	24	11	9	3			7	5	1	2	0	7	5	1	2	0		
p										0.10	0.21	0.09	0.22	0							
SE										0.04	0.08	0.09	0.15	---							
1989				88	28	12	10				3	1	2	0	3	1	2	0			
p											0.03	0.04	0.17	0							
SE											0.02	0.04	0.11	---							
1990					44	37	18					1	3	2	1	3	2				
p												0.02	0.08	0.11							
SE												0.02	0.04	0.08							
1991						34	18						3	2	3	2					
p													0.09	0.11							
SE													0.05	0.08							
1992							33							3	3						
p														0.09							
SE														0.05							
Totals	32	61	111	133	93	96	83	1	9	25	12	5	11	7	23	23	16	6	1	1	0
p[d]															0.07	0.15	0.23	0.17	0.13	0.33	---
SE															0.01	0.03	0.05	0.07	0.13	0.33	---

[a] By years at large is the number of tags shed by the time in years between capture events. Total recoveries by years at large are: 336 for 1 year; 158 for 2 years; 69 for 3 years; 35 for 4 years; 8 for 5 years; 3 for 6 years; and, 0 for 7 years at large.

[b] p is the proportion of tags shed, tags shed/total recoveries.

[c] SE is the standard error of p.

[d] p in this case is the proportion of tags shed for a particular number of years at large, tags shed after x years/total recoveries after x years; where x = 1 through 7 years at large.

Table 9. Summary of age composition estimates, abundance, and standard errors for Arctic grayling ^ 200 mm FL) in Fielding Lake, 1986 through 1993.

	1986[a]					1987[b]					1988[c]				
Age	n[i]	p[j]	SE[k]	N[l]	SE[m]	n	p	SE	N	SE	n	p	SE	N	SE
2	3	0.01	<0.01	38	23	0	---	---	0	---	0	---	---	0	---
3	127	0.25	0.02	1,622	301	16	0.04	0.01	153	49	30	0.04	0.01	322	78
4	50	0.10	0.01	639	137	114	0.25	0.02	1,089	248	201	0.25	0.02	2,158	384
5	31	0.06	0.01	396	96	52	0.11	0.02	497	124	229	0.28	0.02	2,459	433
6	111	0.22	0.02	1,418	268	90	0.20	0.02	860	200	160	0.20	0.01	1,718	311
7	142	0.28	0.02	1,814	333	143	0.31	0.02	1,366	307	116	0.14	0.01	1,245	234
8	51	0.10	0.01	651	140	35	0.08	0.01	334	89	65	0.08	0.01	698	143
9	0	---	---	0	---	6	0.01	0.01	57	26	14	0.02	0.00	150	47
10	0	---	---	0	---	0	---	---	0	---	1	<0.01	<0.01	11	11
Total	515	1.00	---	6,578	1,150	456	1.00	---	4,356	932	816	1.00	---	8,761	1,466

-continued-

Table 9. (Page 2 of 3).

	1989[d]					1990[e]					1991[f]				
Age	n	p	SE	N	SE	n	p	SE	N	SE	n	p	SE	N	SE
2	0	---	---	0	---	36	0.04	0.01	342	74	5	0.01	<0.01	99	47
3	68	0.07	0.01	562	100	266	0.27	0.01	2,527	389	196	0.28	0.02	3,895	752
4	131	0.14	0.01	1,082	171	182	0.18	0.01	1,729	276	189	0.27	0.02	3,756	727
5	327	0.34	0.02	2,700	386	104	0.10	0.01	988	170	82	0.12	0.01	1,630	342
6	235	0.24	0.02	1,941	285	150	0.15	0.01	1,425	232	103	0.15	0.01	2,047	418
7	114	0.12	0.01	941	152	177	0.18	0.01	1,682	269	86	0.12	0.01	1,709	357
8	71	0.07	0.01	586	104	66	0.07	0.01	627	117	35	0.05	0.01	696	170
9	26	0.03	0.01	215	50	11	0.01	<0.01	105	34	9	0.01	<0.01	179	67
10	0	---	---	0	---	1	<0.01	<0.01	10	9	1	<0.01	<0.01	20	20
Total	972	1.00	---	8,027	1,091	993	1.00	---	9,434	1,368	706	1.00	---	14,030	2,576

-continued-

Table 9. (Page 3 of 3).

Age	1992[g] n	p	SE	N	SE	1993[h] n	p	SE
2	4	0.01	<0.01	57	30	5	0.01	<0.01
3	92	0.14	0.01	1,307	315	168	0.27	0.02
4	220	0.34	0.02	3,126	712	174	0.28	0.02
5	126	0.19	0.01	1,790	420	161	0.26	0.02
6	77	0.12	0.01	1,094	268	53	0.09	0.01
7	68	0.10	0.01	966	240	38	0.06	0.01
8	52	0.08	0.01	739	190	15	0.02	0.01
9	13	0.02	<0.01	185	64	3	0.01	<0.01
10	1	<0.01	<0.01	0	---	0	0.00	0.00
Total	653	1.00	---	9,278	2,054	617	1.00	---

[a] Samples taken in 1986 were from seining (37.7%), fyke net (8.3%), and electrofishing (54.0%). Age composition was adjusted for gear selectivity (Clark and Ridder 1987b). Sampling dates were 24 June - 3 July.

[b] Samples taken in 1987 were from seining (5.3%), fyke weir (47.2%), and electrofishing (47.4%). Age composition did not need adjustment for length selectivity (Clark and Ridder 1988). Sampling dates were 16 June - 21 June.

[c] Samples taken in 1988 were from seining (3.5%), fyke weir (5.8%), and electrofishing (90.7%), but were not adjusted for length selectivity (Clark 1989). Sampling dates were 13 June - 20 June.

[d] Samples taken in 1989 were from fyke weir (2.6%),electrofishing (86.7%), and gill net (10.7%) and were not adjusted for length selectivity (Clark 1990). Sampling dates were 22 - 26 June.

[e] Samples taken in 1990 were from fyke weir (7.0%) and electrofishing (93.0%) and were not adjusted for length selectivity. Sampling dates were 12-15 June and 19-21 June.

[f] Samples taken in 1991 were from fyke weir (29.8%) and electrofishing (70.2%) and were not adjusted for length selectivity. Sampling dates were 19-28 June.

[g] Samples taken in 1992 were entirely from electrofishing. Sampling dates were 15 through 20 June.

[h] Samples taken in 1993 were entirely from electrofishing. Sampling dates were 14 through 19 June.

[i] n = sample size.

[j] p = estimated proportion of sample at age.

[k] SE = estimated standard error of p.

[l] N = estimated population size at age.

[m] SE = estimated standard error of N.

Table 10. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 200 mm FL) captured in Fielding Lake, 1986 through 1993[a].

	RSD Category[b]				
	Stock[c]	Quality	Preferred	Memorable	Trophy
1986 (24 June through 3 July)					
Number sampled	218	144	189	0	0
RSD	0.40	0.26	0.34	0.00	0.00
Standard Error	0.02	0.02	0.02	0.00	0.00
1987 (16 through 21 June)					
Number sampled	134	120	217	0	0
RSD	0.29	0.26	0.46	0.00	0.00
Standard Error	0.02	0.02	0.02	0.00	0.00
1988 (13 through 20 June)					
Number sampled	344	225	295	0	0
RSD	0.40	0.26	0.34	0.00	0.00
Standard Error	0.02	0.02	0.02	0.00	0.00
1989 (22 through 26 June)					
Number sampled	379	604	301	0	0
RSD	0.30	0.47	0.23	0.00	0.00
Standard Error	0.01	0.01	0.01	0.00	0.00
1990 (12 through 21 June)					
Number sampled	448	387	328	0	0
RSD	0.39	0.33	0.28	0.00	0.00
Standard Error	0.01	0.01	0.01	0.00	0.00
1991 (19 through 28 June)					
Number sampled	356	240	233	0	0
RSD	0.43	0.29	0.28	0.00	0.00
Standard Error	0.02	0.02	0.02	0.00	0.00
1992 (15 through 20 June)					
Number sampled	272	257	211	0	0
RSD	0.37	0.35	0.28	0.00	0.00
Standard Error	0.02	0.02	0.02	0.00	0.00
1993 (14 through 19 June)					
Number sampled	247	285	198	0	0
RSD	0.34	0.39	0.27	0.00	0.00
Standard Error	0.02	0.02	0.02	0.00	0.00

[a] Sampling dates are in parentheses.
[b] Minimum lengths for RSD categories are (Gabelhouse 1984):
Stock - 150 mm FL; Quality - 270 mm FL; Preferred - 340 mm FL; Memorable - 450 mm FL; and, Trophy - 560 mm FL.
[c] The stock category only represents Arctic grayling size from 200 to 269 mm FL, whereas the stock category determined by Gabelhouse (1984) has a minimum length of 150 mm FL.

Table 11. Estimates of abundance, survival, and recruitment of partially and fully recruited Arctic grayling (≥ 200 mm FL) in Fielding Lake, 1986 through 1992.

Parameter[a]	Partially recruited[b]	SE	Fully recruited[c]	SE
N_{86}	2,657	345	3,883	449
ϕ_{86}	0.65	0.27	0.45	0.10
B_{86}	(52)	602	860	200
N_{87}	1,739	282	2,617	378
ϕ_{87}	0.91	0.89	0.80	0.16
B_{87}	3,352	1,399	1,718	312
N_{88}	4,939	584	3,822	417
ϕ_{88}	0.61	0.23	0.46	0.07
B_{88}	1,356	1,009	1,941	286
N_{89}	4,344	434	3,683	343
ϕ_{89}	0.52	0.28	0.66	0.10
B_{89}	3,000	1,078	1,425	232
N_{90}	5,244	506	3,848	376
ϕ_{90}	0.84	0.43	0.68	0.12
B_{90}	4,867	1,902	2,047	418
N_{91}	9,280	1,101	4,650	580
ϕ_{91}	0.59	0.18	0.41	0.08
B_{91}	759	1,257	1,094	268
N_{92}	6,223	885	2,998	412

[a] Parameter definitions are: ϕ_i = the proportion of marked Arctic grayling that survived from marking in year i to recapture in year $i+1$; N_i = population size of Arctic grayling ≥ 200 mm FL prior to sampling in year i; and, B_i = the number of new Arctic grayling ≥ 200 mm FL that recruited to the population between year i and year $i+1$ and were alive in year $i+1$.

[b] Partially recruited Arctic grayling are defined as age 3 through age 5 fish that are greater than 199 mm FL.

[c] Fully recruited Arctic grayling are defined as age 6 and older fish that are greater than 199 mm FL.

Table 12. Estimates of age (years) and fork length (mm) at maturity for Arctic grayling (≥ 200 mm FL) collected from Fielding Lake in June of 1988 through 1993.

Age	Number Examined	Number Mature	Length Group(mm)	Number Examined	Number Mature
Raw data:					
2	50	0	200-209	152	0
			210-219	228	0
3	818	1	220-229	310	1
			230-239	342	0
4	1,091	39	240-249	327	1
			250-259	338	2
5	1,020	216	260-269	354	1
			270-279	300	4
6	770	530	280-289	346	17
			290-299	302	39
7	593	539	300-309	280	61
			310-319	241	118
8	301	286	320-329	249	160
			330-339	262	214
9	76	74	340-349	253	234
			350-359	264	245
10	4	4	360-369	298	286
			370-379	292	284
			380-389	205	194
			390-399	157	151
			400-409	72	71
			410-429	12	12

Summary statistics[a]:

	Mean	Range		Mean	Range
AM_{01}[b]	4 yrs	3 to 4 yrs	LM_{01}[c]	266 mm	238 to 281 mm
AM_{50}	6 yrs	5 to 6 yrs	LM_{50}	319 mm	308 to 329 mm
AM_{99}	9 yrs	8 to 9 yrs	LM_{99}	383 mm	362 to 426 mm

[a] Summary statistics were calculated from probit analysis (Finney 1971).

[b] AM_x = xth percentile for age at maturity rounded to the nearest 1 year (ranges are the 95% fiducial limits).

[c] LM_x = xth percentile for fork length at maturity (ranges are the 95% fiducial limits).

Table 13. Estimates of sex composition by year for mature Arctic grayling in Fielding Lake, 1987 through 1993.

Year	Males	p	SE	Females	p	SE
1987	175	0.58	0.03	128	0.42	0.03
1988	148	0.43	0.03	198	0.57	0.03
1989	191	0.37	0.02	320	0.63	0.02
1990	251	0.58	0.02	178	0.42	0.02
1991	130	0.53	0.03	114	0.47	0.03
1992	105	0.51	0.03	102	0.49	0.03
1993	163	0.54	0.03	140	0.46	0.03
Total	1,163	0.50	0.01	1,180	0.50	0.01

Table 14. Estimates of abundance of mature Arctic grayling by sex in Fielding Lake, 1986[a] through 1992.

Year	Males	SE	Females	SE	Total	SE
1986	1,696	192	1,656	188	3,352	268
1987	1,358	188	993	137	2,351	232
1988	1,597	149	2,136	200	3,733	250
1989	1,334	105	2,235	176	3,569	205
1990	2,042	186	1,448	132	3,491	228
1991	2,292	254	2,010	222	4,301	337
1992	1,532	181	1,488	176	3,020	252

[a] Sex ratio for 1986 was not estimated, but was assumed to be the average sex ratio for 1987 through 1992 combined. Variance of the sex ratio for 1986 was assumed to be equal to that for 1987 since sample sizes were similar.

Table 15. Estimates of instantaneous mortality rates and bootstrap estimates of standard error for Arctic grayling (^ 200 mm FL) in Fielding Lake, 1986 through 1991.

	Primary statistics[a]				Instantaneous mortality rates[b]					
Year	*N*	u	*B*	*C*	*Z*	SE	*F*	SE	*M*	SE
1986	6,578	0.54	808	1,329	0.62	0.09	0.25	0.11	0.36	0.14
1987	4,356	0.85	5,070	910	0.17	0.08	0.14	0.16	0.03	0.18
1988	8,761	0.54	3,297	1,492	0.62	0.09	0.19	0.10	0.43	0.14
1989	8,027	0.59	4,767	1,283	0.54	0.09	0.16	0.08	0.38	0.12
1990	9,434	0.74	7,013	1,097	0.30	0.10	0.10	0.05	0.20	0.12
1991	14,030	0.53	1,910	1,284	0.64	0.17	0.11	0.05	0.53	0.16
Means	8,609	0.62	3,829	1,232	0.48	0.09	0.16	0.05	0.32	0.10

[a] Primary statistics: *N* = abundance estimate; u = survival rate; *B* = recruitment; and, *C* = harvest. *N*, u, and *B* are from this report and *C* is from Mills (1987-1993). Mean u is the geometric mean u.

[b] Instantaneous mortality rates: *Z* = total mortality; *F* = fishing mortality; *M* = natural mortality; and, SE = bootstrap standard error. *Z* is estimated by $Z = -\ln(u)$, *F* is estimated with the Baranov catch equation (Ricker 1975) with recruitment during fishing, and *M* is estimated by $M = Z - F$.

Age and Growth

A total of 6,134 age and length data pairs was used to estimate means of fork length at age from age 1 to age 10. Standard errors of mean fork length at age were 2 mm or less for all ages except age 10 (Table 16). The von Bertalanffy parameter t_0 was significantly different from zero (t_0 = 0.19, 95% C.I. of 0.02 to 0.37), but was close enough to zero to warrant an analysis with t_0 omitted from the model (Table 17). With t_0 omitted, the estimate of L_∞ was 444 mm FL (SE = 11 mm FL) and the estimate of K was 0.22 (SE = 0.01; Table 17, Figure 3). With t_0 included, L_∞ was 427 mm FL (SE = 10 mm FL) and K was 0.25 (SE = 0.02).

DISCUSSION

Precision and Bias

Capture-recapture sampling of Arctic grayling in Fielding Lake during 1986 through 1993 provided relatively precise and unbiased estimates of abundance, survival, and recruitment for the years 1987 through 1992. Precision (gauged by estimates of CV) in abundance estimates from 1987 through 1989 did not change with the addition of capture data from 1993. However, precision increased 8% and 16% for abundance estimates from 1990 and 1991, respectively, with the addition of capture data from 1993. Similar increases in precision were noted for estimates of survival and recruitment.

Based on goodness-of-fit tests and tests for temporary emigration, estimates of survival for 1986 through 1989 appear to be unbiased. However, both the goodness-of-fit test in 1990 and the test for temporary emigration in 1990 detected a significant difference in recapture rates among fish released prior to 1990. In component 2 of the goodness-of-fit test, the data from 1990 accounts for 59% of the overall chi-squared statistic for component 2. Similarly data from 1990, when stratified by releases of fish during 1986 through 1988 and releases during 1989, accounts for 44% of the overall chi-squared statistic for temporary emigration. One plausible hypothesis that may account for these violations of assumptions is that an influx of small and young fish between 1989 and 1990 caused significant differences in survival rate by age of fish. If this phenomenon had occurred, it may have been temporary since large numbers of younger age fish would have been marked and released in 1990. The strongest year class in 1989 was age 5, while age 3 fish were dominant in 1990 and 1991. If survival rate does vary between age classes, large shifts in age composition between years may bias estimates of survival rate. Up until 1990, ages 5 and 7 were most predominant in Fielding Lake; differences in survival rate of these age classes may be small. From 1990 to 1992, ages 3 and 4 predominate; survival rate may be much higher or lower than for ages 5 and 7. The partitioned data do not indicate significant differences in survival rate between partially and fully recruited age classes, but these data were derived from Jolly-Seber estimates for the entire population. Fortunately, the apparent bias in recovery data appears to diminish after 1990; component 2 tests and tests of temporary emigration do not indicate significant differences in recovery rates after 1990.

Stock Status

The stock of Arctic grayling in Fielding Lake appears to be relatively healthy during the period of stock assessment (1986 to 1993). During this period, there appeared to be no upward or downward trend in recreational harvest of Arctic grayling and in overall fishing effort at the lake. Abundance of Arctic grayling in the lake increased significantly ($\alpha = 0.05$) between 1987 and 1988, but since 1988 has not changed significantly. Survival rate of Arctic grayling increased significantly between 1986 and 1987, decreased significantly between 1987 and 1988, but has not changed significantly since 1988. Recruitment of Arctic grayling into the population increased significantly between 1986 and 1987, but has not changed significantly since 1987. Additionally, new recruits appeared to account for a substantial fraction of total abundance during 1988 through 1990. Forty-one to 57% of estimated abundance during 1988 through 1990 was new recruits. As a result, there have been shifts in age composition of the population since 1988. The population was dominated by age 4 and 5 fish in 1988, shifting to age 5 and 6 fish in 1989, but then shifting to age 3 and 4 fish in 1990 and 1991. In 1992, age composition was weighted towards age 4 and 5 fish. Since ages 3 through 5 have been shown not to have fully recruited, most of the shifts in age composition have come through recruitment. Conversely, age composition of fully recruited Arctic grayling has not changed markedly during the period of stock assessment. Age 6 or 7 fish comprise the strongest fully recruited year-classes in all years of stock assessment. Moreover, abundance of spawners has not changed markedly since 1986.

Fishing mortality rate appeared to decline between 1986 and 1991, mainly through increases in abundance and not decreases in fishing effort. Natural mortality varied greatly between 1986 and 1991, with no apparent trend through time. The average annual exploitation rate during 1986 through 1991 was 13%, while the annual expectation of death was 38%. Based on stock assessment data collected during 1986 through 1992, this rate of exploitation appears sustainable. Clark (in press) found that an exploitation rate of up to 20% produced maximal yields given the current regulations in force at the lake and equilibrium conditions. Recent modeling of Arctic grayling dynamics for the Chena River (unpublished data) indicates that average exploitation rates of 15% or less (over a 20 year period) appear sustainable.

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Table 16. Mean fork length at age of Arctic grayling from Fielding Lake, 1986 through 1993.

Age	n[a]	FL[b]	SD[c]	SE[d]
1	19	78	10	2
2	192	164	24	2
3	1,175	216	28	1
4	1,343	256	30	1
5	1,138	293	30	1
6	965	332	30	1
7	842	359	26	1
8	374	373	22	1
9	82	383	19	2
10	4	385	18	9
Totals	6,134	287	65	1

[a] n is the total number of fish aged from samples taken in 1986 through 1993.
[b] FL is the arithmetic mean fork length in millimeters.
[c] SD is the estimated standard deviation of FL.
[d] SE is the estimated standard error of FL.

Table 17. Parameter estimates and standard errors of the von Bertalanffy growth model with $t_{\grave{e}}$ included and omitted[a] for Arctic grayling from Fielding Lake, 1986 through 1993.

Parameter	Estimate	Standard Error	Coefficient Of Variation
<u>von Bertalanffy with $t_{\grave{e}}$</u>			
$L_{\$}$[b]	427	10	2.3%
K[c]	0.25	0.02	8.0%
$t_{\grave{e}}$[d]	0.19	0.07	36.8%
$Corr(L_{\$},K)$[e]	-0.94	---	---
$Corr(L_{\$},t_{\grave{e}})$	-0.63	---	---
$Corr(K,t_{\grave{e}})$	0.79	---	---
<u>von Bertalanffy without $t_{\grave{e}}$</u>			
$L_{\$}$	444	11	2.5%
K	0.22	0.01	4.5%
$Corr(L_{\$},K)$	-0.94	---	---
Sample size	6,134		

[a] The von Bertalanffy growth model (Ricker 1975) without $t_{\grave{e}}$ is as follows: $l_t = L_{\$}\ (1 - exp(-Kt))$. The applicable range of ages for this model are 1 through 10 years. This model was fitted to the data by nonlinear regression utilizing the Marquardt compromise (Marquardt 1963).

[b] $L_{\$}$ is the length a fish would achieve if it continued to live and grow indefinitely (Ricker 1975).

[c] K is a constant that determines the rate of increase of growth increments (Ricker 1975).

[d] $t_{\grave{e}}$ represents the hypothetical age at which a fish would have zero length (Ricker 1975).

[e] $Corr(x,y)$ is the correlation of parameter estimates x and y.

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APPENDIX A
Age at Full Recruitment

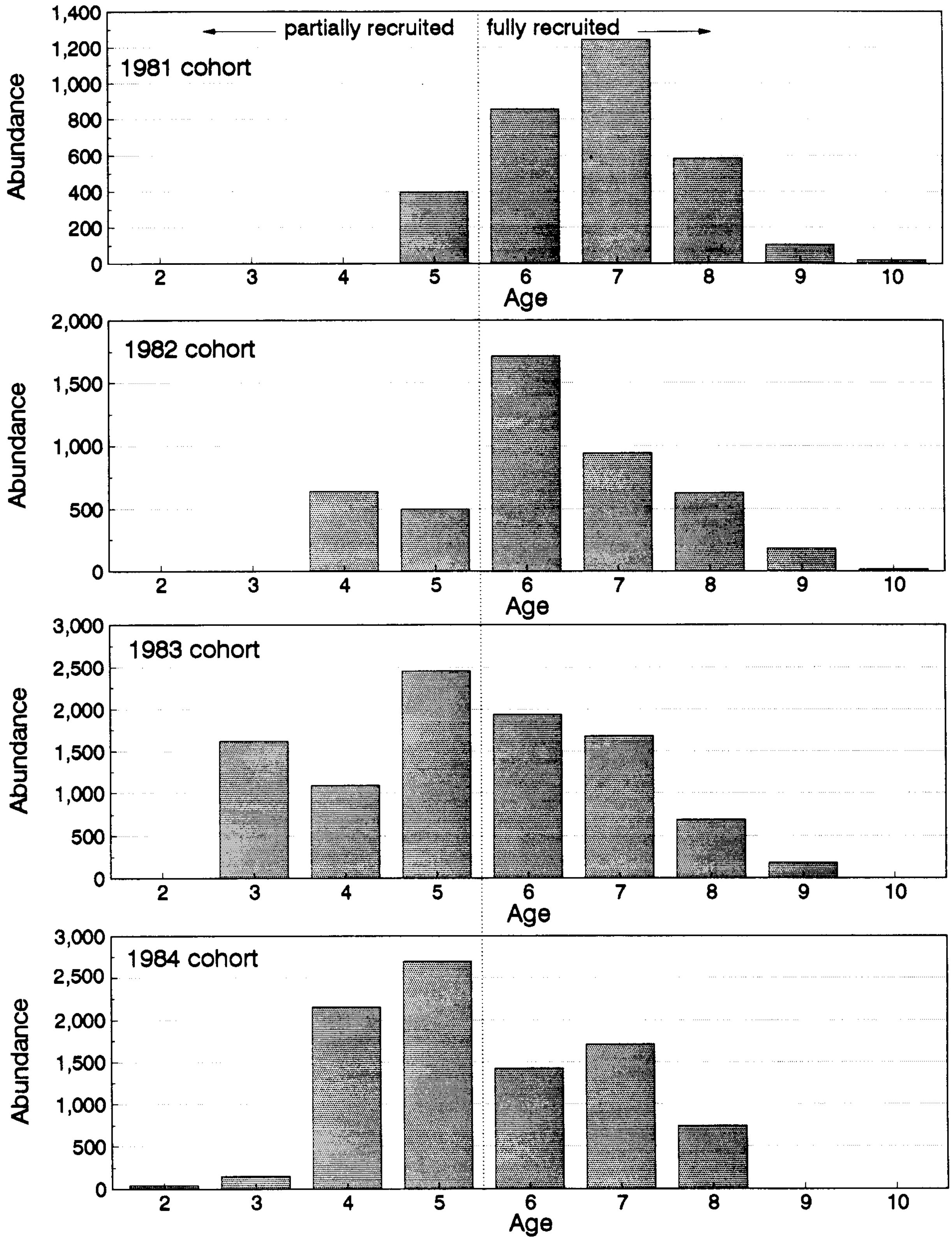
Appendix A1. Summary of age-specific survival rate calculations used to determine age at recruitment into the Arctic grayling population (≥ 200 mm FL) at Fielding Lake, 1986 through 1992.

	1986			1987			1988			1989			1990			1991			1992	
Age	N[a]	SE[b]	ϕ_{86}[c]	N	SE	ϕ_{87}	N	SE	ϕ_{88}	N	SE	ϕ_{89}	N	SE	ϕ_{90}	N	SE	ϕ_{91}	N	SE
2	38	23		0	---		0	---		0	---		342	74		99	47		57	30
			4.03			---			---			---			11.39			13.20		
3	1,622	301		153	49		322	78		562	100		2,527	389		3,895	752		1,307	315
			0.67			14.10			3.36			3.08			1.49			0.80		
4	639	137		1,089	248		2,158	384		1,082	171		1,729	276		3,756	727		3,126	712
			0.78			2.26			1.25			0.91			0.94			0.48		
5	396	96		497	124		2,459	433		2,700	386		988	170		1,630	342		1,790	420
			2.18			3.46			0.79			0.53			2.07			0.67		
6	1,418	268		860	200		1,718	311		1,941	285		1,425	232		2,047	418		1,094	268
			0.96			1.45			0.55			0.87			1.20			0.47		
7	1,814	333		1,366	307		1,245	234		941	152		1,682	269		1,709	357		966	240
			0.18			0.51			0.47			0.67			0.41			0.43		
8	651	140		334	89		698	143		586	104		627	117		696	170		739	190
			0.09			0.45			0.31			0.18			0.29			0.27		
9	0	---		57	26		150	47		215	50		105	34		179	67		185	64
			---			0.19			0.00			0.05			0.19			0.00		
10	0	---		0	---		11	11		0	---		10	9		20	20		0	---
Total	6,578	1,150		4,356	932		8,761	1,466		8,027	1,091		9,434	1,368		14,030	2,576		9,278	2,054

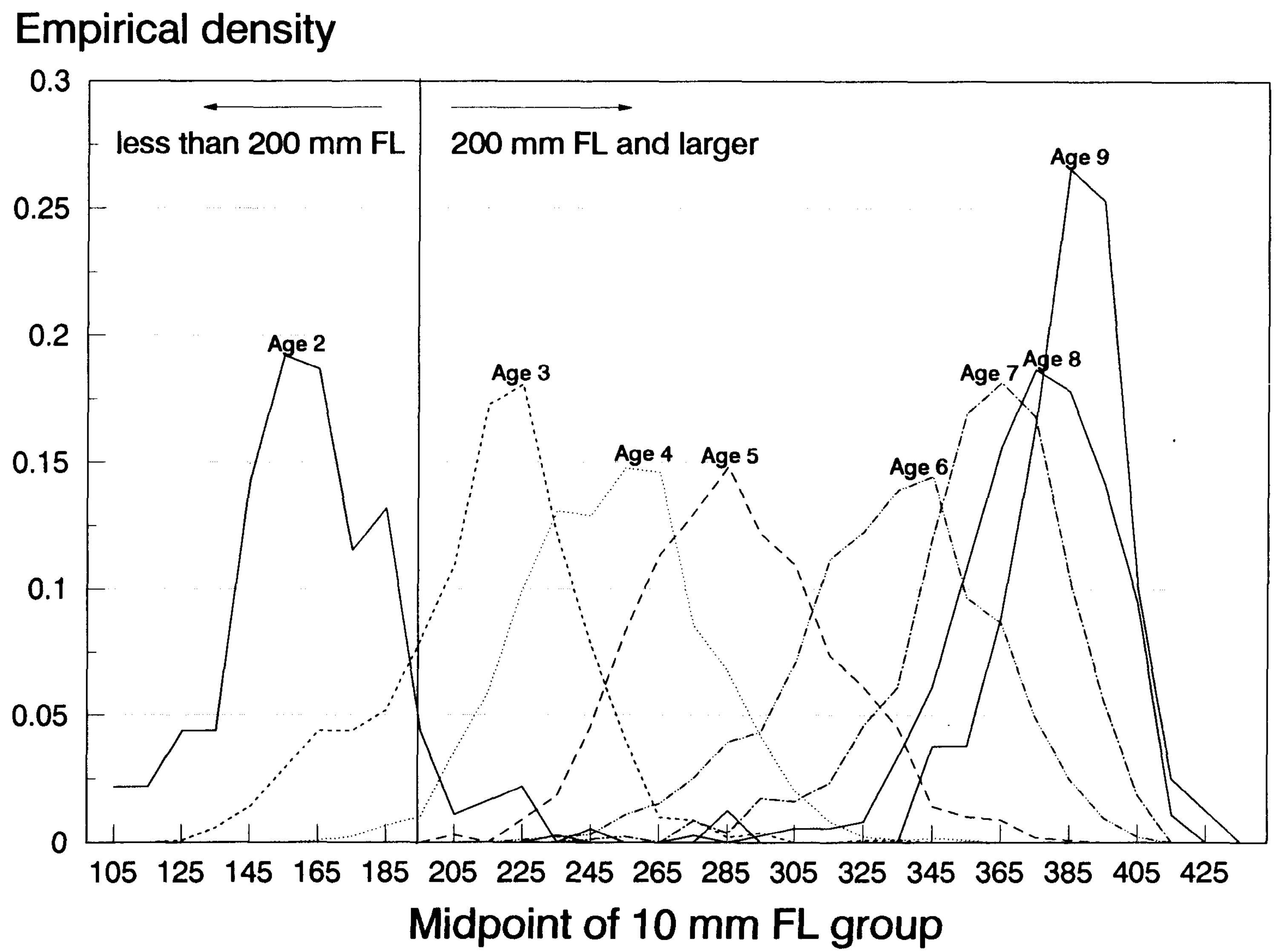
[a] N = age-specific abundance by year.

[b] SE = standard error of age-specific abundance by year.

[c] ϕ_i = age-specific survival rate for the year i through year (i + 1). A survival rate greater than 1.00 is impossible.



Appendix A2. Estimated abundances at age of the 1981 through 1984 cohorts of Arctic grayling in Fielding Lake during 1986 through 1992.



Appendix A3. Empirical density of Arctic grayling fork lengths at age (mm) for ages 2 through 9, calculated from data collected at Fielding Lake from 1986 through 1993.

APPENDIX B
Historic Data Summary

Appendix B1. Summary of Arctic grayling creel surveys at Fielding Lake, 1953 through 1958, 1976, and 1982 through 1987[a].

Year	Dates	Angler Interviews	Angler Hours	Harvest Rate Grayling/hr	Mean Length (mm)
1953	ND[b]	200	1,077	0.50	---
1954	ND	250	1,493	0.49	---
1955[c]	ND	72	277	0.62	348
1956[c]	ND	158	1,073	0.49	348
1957[c]	ND	96	388	0.69	257
1958[c]	ND	75	579	0.34	249
1976	6/15 - 9/4	143	508	0.38	---
1982	7/4 - 9/5	95	288	0.43	336
1983	ND	ND	ND	0.55	325
1984	6/10 - 8/11	43	136	0.46	318
1985	6/30 - 8/25	181	ND	0.34	318
1986	6/24 - 8/31	173	2,374	0.34	304
1987	6/15 - 8/31	162	1,609	0.49	300

[a] Sources are: 1953-1958 from Warner (1959); 1976 from Peckham (1977); 1982 from Peckham (1983); 1983 from Peckham (1984); 1984 from Peckham (1985); 1985 from Holmes et al. (1986); 1986 from Clark and Ridder (1987a); and, 1987 from Baker (1988).

[b] ND = data not available from source document.

[c] A spring closure (closed until 1 July) of the fishery was in effect during these years.

Appendix B2. Distributions of Arctic grayling harvest among interviewed anglers at Fielding Lake, 1986 and 1987.

	1986[a]		1987[b]	
Number harvested	Anglers	p	Anglers	p
0	109	0.65	49	0.55
1	23	0.14	16	0.18
2	15	0.09	10	0.11
3	7	0.04	6	0.07
4	9	0.05	5	0.06
5	4	0.02	3	0.03
Total	167	1.00	89	1.00

[a] Source is Clark and Ridder (1987a).
[b] Source is Clark and Ridder (1988).

Appendix B3. Summary of population estimates of Arctic grayling ($\geq$ 200 mm FL) in Fielding Lake, 1986 through 1992.

Date	Estimator[a]	Estimate	SE
3 July 1986	Petersen[b]	6,578	1,150
16 June 1987	Jolly-Seber[c]	4,356	932
13 June 1988	Jolly-Seber[c]	8,761	1,466
22 June 1989	Jolly-Seber[c]	8,027	1,091
12 June 1990	Jolly-Seber[c]	9,434	1,368
19 June 1991	Jolly-Seber[c]	14,030	2,576
18 June 1992	Jolly-Seber[c]	9,278	2,054

[a] Petersen = the Petersen estimator as modified by Chapman (1951); and, Jolly-Seber = the estimator of Jolly (1965) and Seber (1965).
[b] Source is Clark and Ridder (1987b).
[c] Source is this report. These estimates supersede those of Clark (1993).

Appendix B4. Estimates of age composition of Arctic grayling harvested in the sport fishery from Fielding Lake, 1953 through 1954, 1982, and 1984 through 1987[a].

	Age																			
	1		2		3		4		5		6		7		8		9		10	
Year	n[b]	p[c]	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p
1953	0	0.00	11	0.09	23	0.19	16	0.13	22	0.18	30	0.25	13	0.11	5	0.04	0	0.00	0	0.00
1954	1	0.00	1	0.00	12	0.03	14	0.04	30	0.08	122	0.34	104	0.29	59	0.17	12	0.03	2	0.00
1982	0	0.00	0	0.00	5	0.07	8	0.11	25	0.36	22	0.31	8	0.11	2	0.03	0	0.00	0	0.00
1984	0	0.00	0	0.00	4	0.18	6	0.27	7	0.32	4	0.18	1	0.05	0	0.00	0	0.00	0	0.00
1985	0	0.00	5	0.04	11	0.09	9	0.07	34	0.27	33	0.26	26	0.20	6	0.05	3	0.02	0	0.00
1986	0	0.00	0	0.00	8	0.07	14	0.13	22	0.20	44	0.39	16	0.14	8	0.07	0	0.00	0	0.00
1987	0	0.00	1	0.01	13	0.10	49	0.39	18	0.14	14	0.11	19	0.15	7	0.06	4	0.03	0	0.00

[a] Sources are: Warner (1955a) for 1953 and 1954; Peckham (1983) for 1982; Peckham (1985) for 1984; Holmes, et al. (1986) for 1985; Clark and Ridder (1987a) for 1986; and, Baker (1988) for 1987.

[b] n = number sampled at age.

[c] p = proportion of sample at age.

Appendix B5. Mean fork length (mm) at age of Arctic grayling sampled from Fielding Lake, 1953, 1982, and 1984 through 1993[a].

Age	1		2		3		4		5		6		7		8		9		10	
Year	n[b]	FL[c]	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL
1953[d]	0	---	11	159	23	204	16	245	22	320	30	356	13	347	5	379	0	---	0	---
1982[d]	0	---	0	---	5	247	8	293	25	328	22	358	8	383	2	400	0	---	0	---
1982[e]	ND[f]	124	ND	190	ND	253	ND	312	ND	343	ND	359	0	---	0	---	0	---	0	---
1984[d]	0	---	0	---	4	243	6	275	7	353	4	373	1	385	0	---	0	---	0	---
1985[e]	89	126	75	176	35	217	12	262	9	320	4	341	0	---	2	400	0	---	0	---
1986[d]	0	---	0	---	8	210	14	273	22	301	44	335	16	362	8	381	0	---	0	---
1986[e]	0	---	229	142	409	183	115	240	58	295	99	337	102	362	36	383	0	---	0	---
1987[d]	0	---	1	200	13	237	49	259	18	300	14	347	19	370	7	388	4	396	0	---
1987[e]	21	80	37	121	147	169	129	230	52	291	90	336	143	357	35	377	6	387	0	---
1988[e]	0	---	15	150	62	198	206	236	229	278	160	338	116	360	65	375	14	385	1	370
1989[e]	0	---	50	155	102	208	132	247	327	284	235	315	114	357	71	369	26	384	0	---
1990[e]	0	---	36	161	266	221	182	257	104	283	150	324	177	351	66	371	11	385	1	407
1991[e]	0	---	22	190	218	228	189	265	82	309	104	342	87	360	36	366	9	385	1	370
1992[e]	0	---	40	180	113	222	222	265	125	302	77	346	68	364	52	368	13	373	1	391
1993[e]	0	---	10	191	174	234	174	288	161	321	53	347	38	372	15	379	3	372	0	---

[a] Sources are: Warner (1955a) for 1953; Peckham (1983) for 1982; Peckham (1985) for 1984; Holmes, et al. (1986) for 1985; Clark and Ridder (1987a, 1987b) for 1986; Baker (1988) and Clark and Ridder (1988) for 1987; Clark (1989) for 1988; Clark (1990) for 1989; Clark (1991) for 1990; Clark (1993) for 1991 and 1992; and, this report for 1993.

[b] n = number sampled at age.

[c] FL = mean fork length in mm.

[d] Collected from harvest sample.

[e] Collected from population sample.

[f] ND = data not available from source document.

APPENDIX C

Goodness-of-fit-tests

Appendix C1. Cell values of Jolly-Seber model goodness-of-fit tests[a] performed on capture-recapture data collected from Arctic grayling in Fielding Lake, 1986 through 1993.

Component 1			Component 2			
Row elements	Column elements		Row elements	Column elements		
i = 2 (1987)	First captured before i	First captured in i				
Released and recaptured	5	85				
Expected value	6.2	83.8				
Not recaptured	27	351				
Expected value	25.9	352.1				
i = 3 (1988)	First captured before i	First captured in i		Captured before i-1 not captured in i-1	Captured before i-1 captured in i-1	First captured in i-1
Released and recaptured	11	111	Captured in i	22	3	37
Expected value	8.8	113.2	Expected value	22.4	2.2	37.4
Not recaptured	51	691	Captured after i	29	2	48
Expected value	53.2	688.8	Expected value	28.6	2.8	47.6
i = 4 (1989)	First captured before i	First captured in i		Captured before i-1 not captured in i-1	Captured before i-1 captured in i-1	First captured in i-1
Released and recaptured	15	132	Captured in i	49	6	72
Expected value	14.4	132.6	Expected value	49.9	7.0	70.1
Not recaptured	110	1,019	Captured after i	30	5	39
Expected value	110.6	1,018.4	Expected value	29.1	4.0	40.9
i = 5 (1990)	First captured before i	First captured in i		Captured before i-1 not captured in i-1	Captured before i-1 captured in i-1	First captured in i-1
Released and recaptured	16	83	Captured in i	36	9	88
Expected value	11.6	87.4	Expected value	44.5	9.0	79.5
Not recaptured	115	899	Captured after i	38	6	44
Expected value	119.3	894.7	Expected value	29.5	6.0	52.5
i = 6 (1991)	First captured before i	First captured in i		Captured before i-1 not captured in i-1	Captured before i-1 captured in i-1	First captured in i-1
Released and recaptured	6	46	Captured in i	49	9	35
Expected value	5.8	46.2	Expected value	43.8	8.0	41.2
Not recaptured	85	677	Captured after i	39	7	48
Expected value	85.2	676.8	Expected value	44.3	8.0	41.7
i = 7 (1992)	First captured before i	First captured in i		Captured before i-1 not captured in i-1	Captured before i-1 captured in i-1	First captured in i-1
Released and recaptured	4	29	Captured in i	62	4	30
Expected value	4.3	28.7	Expected value	61.8	4.0	30.2
Not recaptured	91	606	Captured after i	32	2	16
Expected value	90.7	606.3	Expected value	32.2	2.0	15.8

[a] The goodness-of-fit test was devised by Pollock et al. (1985).

Appendix C2. Cell values of tests for temporary emigration[a] performed on capture-recapture data collected from Arctic grayling in Fielding Lake, 1986 through 1992.

Row elements	Column elements	
	Captured in 1988	Captured after 1988
First captured in 1986	22	29
Expected value	22.4	28.6
First captured in 1987	40	50
Expected value	39.6	50.4
	Captured in 1989	Captured after 1989
First captured in 1986	17	12
Expected value	18.0	11.0
First captured in 1987	32	18
Expected value	31.0	19.0
	Captured in 1990	Captured after 1990
First captured in 1986	7	5
Expected value	6.0	6.0
First captured in 1987	8	10
Expected value	9.0	9.0
	Captured in 1991	Captured after 1991
First captured in 1986	3	2
Expected value	3.3	1.7
First captured in 1987	7	3
Expected value	6.7	3.3
	Captured in 1992	Captured after 1992
First captured in 1986	2	0
Expected value	1.6	0.4
First captured in 1987	2	1
Expected value	2.4	0.6
	Captured in 1989	Captured after 1989
First captured in 1986 or 1987	49	30
Expected value	49.9	29.1
First captured in 1988	78	44
Expected value	77.1	44.9

- continued -

Appendix C2. (Page 2 of 3).

Row elements	Column elements	
	Captured in 1990	Captured after 1990
First captured in 1986 or 1987	15	15
Expected value	14.6	15.4
First captured in 1988	21	23
Expected value	21.4	12.6
	Captured in 1991	Captured after 1991
First captured in 1986 or 1987	10	5
Expected value	8.3	6.7
First captured in 1988	11	12
Expected value	12.7	10.3
	Captured in 1992	Captured after 1992
First captured in 1986 or 1987	4	1
Expected value	3.8	1.2
First captured in 1988	9	3
Expected value	9.2	2.8
	Captured in 1990	Captured after 1990
First captured in 1986-1988	36	38
Expected value	44.5	29.5
First captured in 1989	97	50
Expected value	88.5	58.5
	Captured in 1991	Captured after 1991
First captured in 1986-1988	21	17
Expected value	21.2	16.8
First captured in 1989	28	22
Expected value	27.8	22.2
	Captured in 1992	Captured after 1992
First captured in 1986-1988	13	4
Expected value	10.9	6.1
First captured in 1989	12	10
Expected value	14.1	7.9

- continued -

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Row elements	Column elements	
	Captured in 1991	Captured after 1991
First captured in 1986-1989	49	39
Expected value	43.8	44.2
First captured in 1990	44	55
Expected value	49.2	49.8
	Captured in 1992	Captured after 1992
First captured in 1986-1989	25	14
Expected value	25.7	13.3
First captured in 1990	37	18
Expected value	36.3	18.7
	Captured in 1992	Captured after 1992
First captured in 1986-1990	62	32
Expected value	61.8	32.2
First captured in 1991	34	18
Expected value	34.2	17.8

[a] The tests for temporary emigration were devised by Balser (1981).

APPENDIX D
Data File Listing

Appendix D1. Data files[a] used to estimate parameters of the Arctic grayling population in Fielding Lake, 1986 through 1993.

Data file	Description
U0013ABA.DTA	Population and marking data for Arctic grayling captured in Fielding Lake (all areas) in 1986.
U013BBA7.DTA	Population and marking data for Arctic grayling captured in Fielding Lake (in the lake itself) by electrofishing in 1987.
U013GBB7.DTA	Population and marking data for Arctic grayling captured at Caribou Bay Creek with fyke nets in 1987.
U013HBA7.DTA	Population and marking data for Arctic grayling captured at Two Bit Creek with fyke nets in 1987.
U013IBA7.DTA	Population and marking data for Arctic grayling captured at Fielding Lake outlet with seines in 1987.
U013BLA8.DTA	Population and marking data for Arctic grayling captured in Fielding Lake (in the lake itself) with electrofishing in 1988.
U013FLA8.DTA	Population and marking data for Arctic grayling captured at Two Bit Creek with fyke nets in 1988.
U013GLA8.DTA	Population and marking data for Arctic grayling captured at Caribou Bay Creek with fyke nets in 1988.
U013ILA8.DTA	Population and marking data for Arctic grayling captured at Fielding Lake outlet with seines in 1988.
U013BLA9.DTA	Population and marking data for Arctic grayling captured in Fielding Lake (in the lake itself) with electrofishing in 1989.
U013GLA9.DTA	Population and marking data for Arctic grayling captured at Two Bit Creek with fyke nets in 1989.
U013ELA0.DTA	Population and marking data for Arctic grayling captured at Fielding Lake (all areas) in 1990.
U013GLA1.DTA	Population and marking data for Arctic grayling captured at Fielding Lake (all areas) in 1991.
U013ALA2.DTA	Population and marking data for Arctic grayling captured at Fielding Lake (all areas) in 1992.
U013OLA3.DTA	Population and marking data for Arctic grayling captured at Fielding Lake (all areas) in 1993.

[a] Data files have been archived at, and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1599.